Air Transport And Deposition of Actinides for the Actinide Migration Evaluation at the Rocky Flats Environmental Technology Site

FY00 Report

September 2000

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EXECUTIVE SUMMARY

The Rocky Flats Environmental Technology Site (RFETS or Site) has been a source of airborne actinides throughout its history. Over time, small amounts of plutonium, americium, and other actinides have been deposited on or mixed with surface soils at the Site. Wind or mechanical disturbance of the contaminated soil can result in actinide-laden soil particles becoming airborne. These resuspended particles, along with particles emitted from building stacks and vents, are transported some distance downwind before being deposited on the ground or in water by a variety of mechanisms that remove particles from the air. As a result, airborne migration is one of several transport pathways that redistribute actinides in the environment in the vicinity of the Site.

Prior to 1989, the Site fabricated nuclear weapons components from plutonium, uranium, beryllium, and stainless steel. Weapons operations were curtailed at the Site in 1989 due to safety concerns, and in February 1992, the Site's weapons production mission was discontinued.

The Site is now undergoing deactivation, decommissioning, and cleanup, and is moving toward final closure. Closure of the Site entails removal of nuclear material and waste products, which are being shipped to off-Site repositories and disposal facilities. Buildings will be removed and areas of contamination cleaned up. Clean fill dirt will be brought in from off Site to cover remaining building foundations and structures. The Site is expected to be dedicated to open space use following closure.

During fiscal year 1999 (FY99), a Site-specific emission estimation method was developed that allows calculation of actinide emissions due to resuspension of contaminated soil particles by wind. The estimation method was based on wind speed, size of the contaminated areas, and surface soil concentrations of actinides within each contaminated area. A Site-specific implementation of the U.S. Environmental Protection Agency's (EPA's) Industrial Source Complex Short-Term dispersion and deposition model (ISCST3) was developed, which incorporated the processing of one year of on-Site meteorological data. The emission estimation technique and model were used to calculate impacts from soil resuspension under existing Site conditions (pre-closure).

The focus of the FY00 work was to use the atmospheric dispersion and emission estimation techniques developed in FY99, and refined as part of the FY00 work, to investigate the impact of specific activities on airborne actinide concentration/dose and actinide deposition. As Site closure proceeds, remediation projects and building decontamination and decommissioning (D&D) will result in actinide emissions to air as contaminated soils or material are disturbed. Other situations that could result in elevated actinide levels in air include wildfires, post-fire resuspension, and high wind events. The FY00 work estimated emissions and dispersion from these activities, with the goal of generating reasonable upper bound values.

The FY00 work also estimated the airborne actinide concentrations and deposition that would result from normal resuspension processes following Site closure, assuming an absence of significant soil disturbance (consistent with open space use). The potential effect of periodic disturbances on resuspension following Site closure was also reviewed. An additional area of investigation was to see if gradual outward migration of very small amounts of actinides over long periods of time would have measurable consequences for population exposure.

The scenarios that were investigated and the results of those analyses are summarized below.

Scenario 1: Resuspension Under Current Site Conditions

This scenario was essentially the same as that modeled for the FY99 report, but with a number of improvements made to the methods used. The scenario looked at the effects of wind resuspension of contaminated soils, using existing surface soil contaminant patterns and assuming no disturbance of the soil by traffic, excavation, etc.

Description

The refinements that were made to the modeling methods included:

- **Depletion of the plume to account for deposited material.** The FY99 model runs did not remove the particulate matter (and actinide) that was deposited to the ground from the airborne particulate plume. Therefore, some of the mass was "double counted", which increased the predicted airborne concentrations and effective dose equivalents in an unrealistic manner. The simplification was made in FY99 because the deposition algorithm in the ISCST3 model required significant computational resources. An optimized deposition algorithm has since been added to the ISCST3 model by EPA; this optimized algorithm allowed a more realistic treatment of plume depletion in the FY00 model runs.

- **Particle density.** The FY99 report assumed a uniform particle density across all particle size classes. For the FY00 model simulations, particle densities were revised based on a theoretical breakdown for generic soil that is consistent with soil data taken in the Woman Creek drainage and near the South Interceptor Ditch on Site.

- **Revised soil actinide distribution maps.** During FY99, surface soil actinide concentration data were reanalyzed by other researchers. The isopleths reflecting the revised distribution were used in the FY00 air pathway modeling.

Results

Scenario 1 was used as the basis for an expanded comparison of model predictions with measured actinide levels around the Site. The comparison indicated that modeled wind erosion still overpredicted airborne actinide concentrations in the predominant downwind directions but may underpredict measured concentrations upwind to some extent. Overall, model predictions were improved relative to the FY99 modeling.

Scenario 2: 903 Pad Remediation

The most significant soil contamination areas contributing to airborne actinides at the Site are the 903 Pad and the adjacent "lip" area. The 903 Pad was contaminated with plutonium-laden cutting oil stored in metal drums, which leaked over time into the soil beneath the drums. Removal of the drums in the late 1960s and associated cleanup activities resulted in dispersion of contaminated soil to the east and to the south of the 903 Pad. The storage pad was covered with asphalt in 1969, and is no longer a source of resuspendable actinides. However, the initial spread of the contaminated soil prior to the installation of the asphalt pad resulted in a plume of actinides in the surface soils extending to the east and southeast from the 903 Pad itself.

As part of the Site closure strategy, the asphalt pad covering the former drum storage area will be removed and the underlying soils remediated. Remediation activities, designed to reduce soil contamination at the Site to below negotiated action level criteria, will result in short-term emissions of actinides as contaminated soil is disturbed through excavation, handling, and disposal. While such cleanup activities will reduce future actinide migration potential by eliminating or reducing the source, fugitive emissions during remediation may result in short-term increases in exposure through the air pathway, as well as redeposition of actinide containing particles downwind.

Description

Because the 903 Pad area has the highest surface soil concentrations of plutonium and americium at the Site, cleanup of this area was chosen for modeling. Both an annual scenario, representing a chronology of remediation activity over a 1-year period, and a short-term, high wind event, were modeled.

The annual scenario was designed to represent a reasonable "worst-case" remediation situation. Emissions were maximized for the simulation by assuming that the remediation activities would take place with only minimally required control measures, such as watering to prevent fugitive dust. (The details of the actual remediation plan for the 903 Pad are still under review, but will almost certainly include additional emission control measures beyond those factored into this modeling exercise.)

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A second scenario looked at emissions from remediation activities during a high wind event. This scenario simulated a windy 24-hour period during the hypothetical 903 Pad remediation project when soil disturbance would be at a maximum. Consequently, particulate matter and actinide concentrations and deposition were predicted for a 24-hour period. The meteorological data used were based on the maximum recorded winds at the Site during the most recent four years.

Results

The results of the 903 Pad remediation modeling indicated that annual average particulate matter and actinide concentrations would be well within applicable air standards for a remediation project conducted according to the assumptions made. Use of additional fugitive dust control measures, such as a weather enclosure, would further lessen ambient concentrations of both particulate matter and actinides. Deposition of actinides to ground or surface water would also be reduced.

Conversely, excavation of larger amounts of contaminated soil would increase airborne actinides and actinide deposition. Cleanup to more restrictive levels, for example, would result in excavation of additional soil, thereby increasing airborne actinide concentrations and deposition.

Maximum annual actinide and particulate matter concentrations during remediation would occur at or very near the remediation site. Airborne concentrations of dust and actinides would generally decrease with distance from the work area.

The short-term, high wind event showed much lower maximum concentrations and deposition than the annual remediation scenario. The reduced impacts during high winds were partly a result of enhanced dispersion—pollutants are spread throughout a greater volume of air as wind speed increases. More importantly, the reduced impacts reflected the fact that emission sources such as excavation and traffic would not be active (i.e., would not emit) during high winds, even though wind speed-dependent emissions would increase.

Scenario 3: Decontamination and Decommissioning (D&D) Release

In general, D&D activities are not expected to result in significant actinide emissions. Decontamination projects, such as the removal of equipment and materials from buildings scheduled for demolition, will generally be conducted within intact building shells. Activities with significant emission potential will occur within areas that vent through high efficiency particulate air (HEPA) filters, which will reduce any potential emissions to the environment to negligible levels. Building surfaces will normally be decontaminated before the building is actually demolished.

Description

This scenario was designed to simulate the release of an unexpected "pocket" of actinides trapped in a crack or other portion of a concrete wall or support. In this case, the release would occur when the concrete structure is demolished and subsequently crushed.

Results

The release of a highly contaminated pocket of concrete during D&D could result in relatively high, but short-lived, airborne actinide concentrations. The maximum impacts would occur very close to the release point. Concentrations at the facility fenceline would be several orders of magnitude less.

Scenario 4: Wildfire and Post-Fire Enhanced Resuspension

One situation that has generated public concern in the past regarding actinide emissions is a wildfire. Lightning has caused three small grass fires at the Site in recent years and the Site will always be subject to potential fire from this or other ignition sources. A fire would cause a short-term release of actinides from contaminated soil attached to vegetation surfaces and from any actinides that might have been taken up into plant tissues in portions of the Site where soil contamination exists in the root zone. In addition, the burned area would be subject to enhanced wind resuspension of ash and soil particles for some period following a fire. Both these circumstances were addressed in the FY00 work.

Description

The 903 Pad area was chosen as the modeling location for the wildfire and post-fire scenarios. Wildfires resulting from presumed lightning strikes were modeled under two discrete sets of assumptions from which short-term (i.e., fire-released) and longer-term (i.e., exposed soil erosion) actinide emission rates were estimated. One wildfire configuration simulated the current conditions at the Site, with the 903 Pad covered in asphalt and not available as fuel for a wildfire. The other configuration was the post-closure condition in which the 903 Pad was assumed to be unpaved and revegetated following remediation. Both fires were modeled as having occurred in late September of a very dry year, when maximum fuel load would be present. The fires were assumed to consume a limited area (109 acres) before being stopped by emergency responders.

A second concern is the removal of vegetation in contaminated areas by wildfires. The bare ground may be subject to disturbance and wind erosion until the vegetation recovers. Scenarios were modeled representing gradual recovery from wildfires assuming both pre-closure and post-closure soil contamination levels.

The mechanism for resuspension of soil particles and, thereby, actinides from the burned area following a wildfire is essentially the same as that for chronic soil resuspension (Scenario 1). The difference is the assumed increased rate of wind erosion and particulate emissions from unprotected (i.e., unvegetated) soil. Multipliers were developed and applied to the Scenario 1 resuspension equation to estimate post-burn particulate and actinide emissions.

To assess the potential influence of post-fire resuspension rates on actinide concentrations, a comparison study was performed. To provide a base case, the acreage in question was initially modeled with the wind-driven resuspension equation identified in Scenario 1 without applying any multipliers. In other words, the impacts were determined for this limited area assuming no influence of fire.

The acreage in question was then modeled using the multiplier-adjusted particulate and actinide emissions. The particle size distribution and activity distribution were also revised for the post-fire model runs based on recent research conducted by Ranville et al. (2000) using Site soils. The impacts from the post-fire runs were compared to the paired base case results to determine the affect of enhanced post-fire resuspension on annual actinide concentrations.

Results

Both fire scenarios (pre-closure and post-closure contaminant levels) show high particulate matter concentrations within the plume, but for a relatively short period of time. The maximum particulate matter concentrations predicted within the wildfire plume were comparable to those measured by researchers in forest fire plumes. Maximum particulate matter and actinide concentrations would occur under low wind speed, stable conditions because these conditions would produce a slower-moving fire, with a cooler plume that would not readily disperse.

The post-closure fire would produce slightly higher particulate and actinide concentrations than the pre-closure fire. The 903 Pad is not currently a source of fuel or actinide emissions because it is paved. Cleanup would lower soil actinide levels, but would also expose the soil under the pad. Under the post-closure scenario, the 903 Pad area was assumed to be revegetated; therefore, this area would represent an additional fuel and actinide source for the post-closure fire, which would increase impacts.

The post-fire resuspension scenarios showed that over the course of a year, a reasonable worst-case vegetation recovery scenario would result in a five-fold increase in actinide concentrations when compared to unburned conditions. The speed with which vegetative recovery would occur can affect the concentrations and resulting dose estimates substantially—the faster the recovery, the smaller the resulting increase in pollutant concentrations and effective dose equivalents.

As with the fire scenarios, the post-closure vegetative recovery scenarios showed somewhat higher concentrations than the pre-closure scenarios. This results from the 903 Pad itself becoming a resuspension source after the asphalt covering has been removed.

Scenario 5: Post-Closure Chronic Resuspension

This scenario looked at annual actinide concentrations due to chronic resuspension of contaminated soils following closure of the Site. This scenario was essentially Scenario 1 redone to take into account post-closure differences in soil contamination and surface characteristics affecting wind erosion.

Description

Following closure of the Site, the expected use for most of the acreage is as open space. The Rocky Flats Cleanup Agreement establishes contractually required cleanup criteria for the Site. This scenario looked at wind-driven resuspension from the post-closure Site. The differences from Scenario 1 were that soil contamination hot spots were assumed to be gone and Site buildings and pavement were assumed to have been removed.

Results

Maximum post-closure impacts were predicted to occur just to the east or southeast of the primary remaining areas of surface soil contamination on Site. Based on the comparison of model results with sampling data performed in conjunction with Scenario 1, the maximum impacts from this scenario were probably overestimated.

Post-closure impacts may be slightly higher than pre-closure impacts. Maximum (on-Site) concentrations could increase by a factor of two to three over pre-closure impacts, while at the fenceline, the increase would be more modest (less than a 50% increase).

Remediation of the 903 Pad area and cleanup of soil contamination under buildings are important components of Site closure. Remediation projects will decrease actinide concentrations in Site soils, thereby decreasing the total actinides available in the Site environment. However, removal of buildings and pavement will increase the area available for wind erosion. Although only small amounts of actinides will be left in Site surface soils following closure, particles and actinides would be resuspended from a significantly larger area, with resulting increases in impacts to air. The maximum post-closure concentrations that were predicted would still be well within regulatory limits and would represent less than 2% of the average annual radiation dose received by residents of the Denver area from all sources.

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Other Investigations

Three additional investigations were carried out as part of the FY00 air pathway work:

1) **High winds.** Public discussions have identified high winds, including chinooks and possible tornadoes, as events that could resuspend large amounts of soil and actinides. However, there is a trade-off between resuspension and dispersion. As wind speeds increase, more soil and actinides will be resuspended, which would tend to increase ambient actinide concentrations. Higher winds also improve dispersion, however, resulting in increased dilution of the suspended soil and actinides. The relationship between these two conflicting influences was explored in this scenario. It was determined that the increase in resuspension emissions would outweigh the improved dispersion under high wind conditions.

2) **Periodic disturbance.** As discussed above, the post-closure Site was assumed to be devoted to open space uses, with no active soil disturbances occurring (i.e., no excavation, no mining, no construction activities, etc.). The relative effect that periodic disturbances would have on post-closure airborne actinide concentrations was explored in this investigation. Generally, emissions and impacts would increase in proportion to the frequency of disturbance and the size of the areas disturbed.

3) **Long-term chronic resuspension.** Small amounts of actinides will remain in Site soils after closure, since it would be impossible to physically remove all soil contamination. Instead, contaminated soils will be cleaned up to negotiated levels. The remaining contaminated surface soils will be subject to ongoing resuspension and deposition. The net result is that over long periods of time (hundreds to thousands of years), some fraction of the contaminated soils will move out into surrounding communities and contribute to airborne concentrations over wider areas. This investigation looked at this phenomenon over a 1,000-year period to determine whether the resulting population exposure would be measurable.

A number of analyses were performed to generate estimates of future dose to the surrounding population. A reasonable lower bound scenario predicted slight increases in collective dose following Site closure, while other assumptions predicted higher levels. The study concluded that additional data regarding changes in surface soil actinide concentrations over time would be needed before estimates of future collective dose can be refined.

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Conclusions

The FY00 work was designed to investigate emission scenarios and events that may be of interest with regard to actinide migration during and after Site closure. The scenarios were not intended to provide definitive data regarding specific remediation or D&D projects because many pertinent details of those actions are still undergoing review and refinement. Instead, the modeling was intended to provide reasonable upper bounds for the expected impacts of closure activities and post-closure Site configurations. The conclusions reached from the FY00 scenario modeling effort are summarized below.

- Resuspension from undisturbed vegetated surfaces at the Site would result in small airborne actinide concentrations and modest amounts of deposition. Post-closure impacts would increase somewhat with removal of paved areas and buildings, but the estimated impacts would still be well within regulated levels. Periodic disturbances would increase impacts in proportion to their frequency and the amount of surface area involved.

- Remediation would result in short-term increases in both particulate matter and actinide concentrations in air. The scenario modeled for this report would not result in particulate matter or actinide levels that would exceed federal or Colorado standards. The inclusion of additional particulate matter controls could lower impacts further, while cleanup to more restrictive standards would increase impacts.

- The release of an unexpected "pocket" of contaminated concrete during D&D could result in relatively high but very short-lived impacts. Maximum impacts would occur very near the point of release, within Site boundaries, and impacts at the fenceline would be several orders of magnitude lower.

- A wildfire could result in high, short-term particulate matter concentrations. The significance of the impacts would depend both on the size of the burned area and the weather conditions during the fire. Light winds and stable conditions would contribute to higher pollution levels at the ground than windy conditions, although a wildfire is likely to burn a much larger area under high winds. Airborne actinide concentrations would vary depending on where on the Site the fire occurs.

- Post-fire resuspension would increase from the burned areas. Under reasonable worst-case vegetative recovery conditions, a five-fold increase in annual emissions would occur relative to unburned areas.

- High winds can resuspend much larger amounts of particulate matter and actinides than lower wind speeds, with resulting increases in downwind

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concentrations. The effect of increasing wind speed on emissions is particularly pronounced if the ground surface has been disturbed by traffic or excavation or any other natural or man-induced event that renews the erodible surface layer of soil.

- Over a very long time, actinide migration from the Site through the air pathway may increase public exposure and dose. While scenarios can be envisioned that would increase public exposure substantially, realistic projections show an increase of between a few percent to less than a factor of four. This projected increase applies to the collective dose to the surrounding population; individual dose is not expected to increase over the long term. Additional population growth in the immediate Site vicinity would be expected to increase collective exposure and dose.

Recommendations for Future Work

The model developed in the FY99 work and refined in FY00 will be used along with other models for air regulatory compliance planning associated with proposed cleanup alternatives at the Site. For example, the model can be used to show comparative impact levels for various scenarios and control techniques. It is expected that additional modeling will be performed using the techniques outlined here as remediation or D&D projects at the Site proceed into the detailed planning phase and specific decisions are made regarding alternative strategies.

While the air dispersion and emission estimation techniques used in the FY00 work represents a significant improvement over the FY99 tools, the technique would benefit from additional data in some areas. Several investigations are planned or are ongoing that will be used to improve model accuracy and precision, as well as to refine the assumptions used in modeling specific activities. Two general areas of investigation are described below.

- **Wind tunnel investigation of resuspension and post-fire recovery:** During the past two years, the Site has planned and evaluated a program of annual prescribed burns to reduce the buildup of flammable litter, restore native grasses, and control noxious weeds in portions of the Site. Several prescribed burns were planned for the Spring of 2000 and a 50-acre test burn was conducted in April. Kaiser-Hill developed and implemented a wind tunnel investigation in conjunction with the planned burns. The purpose was to measure resuspension of soil and ash immediately following a burn and at intervals after the burn to determine how the resuspension rates varied from those measured over unburned, undisturbed areas of the Site.

Because of a small grass fire caused by lightning at the Site in July 2000, additional wind tunnel investigations were also implemented. The grass fire burned an area with low levels of actinide contamination. The additional wind tunnel study gathered data on particle and actinide activity in different size fractions of resuspended material and in the underlying soil.

Kaiser-Hill contracted with Midwest Research Institute (MRI) to perform the wind tunnel studies, using the same wind tunnel configuration that formed the basis for the chronic, natural resuspension emission factor developed in the FY99 air pathway work. Consequently, the FY00 wind tunnel measurements should provide additional data with which to refine the emission estimating technique, as well as provide new information regarding post-fire recovery. Wind tunnel data will be available in Fall 2000 and will be used to refine model estimates in FY01.

- **Roadway dust sampling:** One of the assumptions made in the FY99 air pathway investigation was that paved and unpaved roadways on Site were not sources of resuspendable actinides. This assumption was questioned by reviewers because no measurement data were available to confirm the assumption. If the roads in the vicinity of the 903 Pad contain measurable amounts of actinides in surface dust, the omission of this source from the modeling could lead to inaccurate results. Traffic is the single largest source of particulate emissions on Site, and any actinides in dust on unpaved or paved road surfaces could result in airborne actinide emissions, as well as contribute to surface loading of actinides on nearby vegetation.

  As a result, direct measurement of actinide concentrations in road dust collected in the vicinity of the 903 Pad is planned for FY01. The results may be used to revise the air pathway modeling if the FY00 results and the results of the dust measurement program suggest that further modeling is warranted.

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Abbreviations and Acronyms

Am	Americium
AP-42	Compilation of Air Pollutant Emission Factors (EPA, 1995b)
BLM	U.S. Bureau of Land Management
CAP88	Clean Air Act Assessment Package-1988 (Version 1.0)
CDPHE	Colorado Department of Public Health and Environment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
Ci	Curie(s)
Ci/m^3	Curies per cubic meter
cm	Centimeter(s)
cm^2	Square centimeter (s)
cm^3	Cubic centimeter(s)
°C	Degrees Celsius
D&D	Decontamination and decommissioning
DOE	U.S. Department of Energy
Dpm	Disintegrations per minute
EDE	Effective dose equivalent
EF	Emission factor
EPA	U.S. Environmental Protection Agency
ft	Foot (feet)
FY	Fiscal year
°F	Degrees Fahrenheit
g	Gram(s)
g/cm^3	Grams per cubic centimeter
g/g	Gram per gram
g/m^2	Grams per square meter
$g/m^2/s$	Grams per square meter per second
$g/m^2/yr$	Grams per square meter per year
g/s	Grams per second
g/VKT	Grams per vehicle kilometer traveled
g/VMT	Grams per vehicle mile traveled
HEPA	High efficiency particulate air (filters)
HPGE	High purity germanium
hr	Hour(s)
H_2O_2	Hydrogen peroxide
ISC3	Industrial Source Complex model, Version 3
ISCST3	Industrial Source Complex model, Short-Term
K	Kelvin
Kaiser-Hill	Kaiser-Hill Company, L.L.C.
kg	Kilogram(s)
kg/m^3	kilograms per cubic meter
kg/Mg	kilograms per megagram
km	Kilometer(s)
km^2	Square kilometer(s)

Abbreviations and Acronyms (continued)

km/hr	Kilometers per hour
lb	Pound(s)
lb/hr	Pounds per hour
lb/VMT	Pounds per vehicle mile traveled
m	Meter(s)
m^2	Square meter(s)
m^3	Cubic meters(s)
m^3/yr	Cubic meters per year
Mcal/kg	Megacalorie per kilgram
MEI	Maximally exposed individual
mg	Milligram(s)
mg/g	Milligrams per gram
Mg	Megagram(s)
mph	Mile(s) per hour
MPRM	Meteorological Processor for Regulatory Models
mrem	Millirem
mrem/yr	millirem per year
MRI	Midwest Research Institute
m/s	Meter(s) per second
NAAQS	National Ambient Air Quality Standards
NWS	National Weather Service
OU3	Operable Unit 3
Person-rem/yr	Person-rem per year
pCi	Picocurie(s)
pCi/g	Picocuries per gram
$pCi/m^2/s$	Picocuries per square meter per second
$pCi/m^2/yr$	Picocuries per square meter per year
pCi/m^3	Picocuries per cubic meter
pCi/s	Picocuries per second
PM	Particulate matter
$PM_{2.5}$	Particulate matter < 2.5 micrometers
PM_{10}	Particulate matter < 10 micrometers
PM_{30}	Particulate matter < 30 micrometers
Pu	Plutonium
RAAMP	Radioactive Ambient Air Monitoring Program
RCRA	Resource Conservation and Recovery Act
Rem	Roentgen equivalent man
RESRAD	Residual Radioactive Material Model
RFCA	Rocky Flats Cleanup Agreement
RFETS	Rocky Flats Environmental Technology Site
RFFO	Rocky Flats Field Office
RMRS	Rocky Mountain Remediation Services, L.L.C.
s. sec	Second(s)
SASEM	Simple Approach Smoke Estimation Model

Abbreviations and Acronyms (continued)

SID	South Interceptor Ditch
Site	Rocky Flats Environmental Technology Site
T-3/T-4	Trench 3/Trench 4
TSP	Total suspended particulates
U	Uranium
USFS	U.S. Forest Service
UTM	Universal Transverse Mercator
VKT	Vehicle kilometers traveled
VMT	Vehicle miles traveled
yd^3	Cubic yard(s)
yr	Year
$\mu g/m^3$	Micrograms per cubic meter
µm	Micrometer(s)

1.0 INTRODUCTION

The Rocky Flats Environmental Technology Site (RFETS or Site) has been a source of airborne actinides throughout its history. Over time, small amounts of plutonium (Pu), americium (Am), and other actinides have been deposited on or mixed with surface soils at the Site. Wind or mechanical disturbance of the contaminated soil can result in actinide-laden soil particles becoming airborne. These resuspended particles, along with particles emitted from building stacks and vents, are transported some distance downwind before being deposited on the ground or in water by a variety of mechanisms that remove particles from the air, such as rainout or dry deposition. As a result, airborne migration is one of several transport pathways that redistribute actinides in the environment in the vicinity of the Site (other primary pathways include soil erosion, and surface and groundwater movement).

During fiscal year 1999 (FY99), a Site-specific emission estimation method was developed that allows calculation of fugitive particulate and associated actinide emissions due to resuspension of contaminated soil particles by wind. The estimation method was based on wind speed, size of the contaminated areas, and surface soil concentrations of actinides within each contaminated area. A Site-specific implementation of the U.S. Environmental Protection Agency's (EPA's) Industrial Source Complex Short Term (ISCST3) dispersion and deposition model was developed and one year of meteorological data was processed for use with this model. Preliminary modeling suggested several improvements that could be made to the emission and modeling methods based on a comparison of modeled impacts to measured airborne actinide levels at the Site.

For FY00, several refinements have been made to the modeling approach. The resulting emission estimating method and Site-specific model implementation were used to simulate emissions and dispersion from several types of activities that could result in airborne particulate and actinide emissions. This report summarizes the FY00 air pathway investigations and results.

1.1 Background

The Rocky Flats Environmental Technology Site is operated by Kaiser-Hill Company, L.L.C. (Kaiser-Hill), with oversight by the Rocky Flats Field Office (RFFO) of the U.S. Department of Energy (DOE). The Site occupies an area of 26.5 square kilometers (km^2) in northern Jefferson County, Colorado, about 25.7 kilometers (km) northwest of Denver. Over 2.1 million people live within 80 km of the Site. Adjacent land use is a mixture of agriculture, open space, industry, and residential housing. Surrounding communities include the city of Golden to the south of the Site; the cities of Arvada, Broomfield, and Westminster to the east; and the city of Boulder to the north. Figure 1-1 shows the Site location.

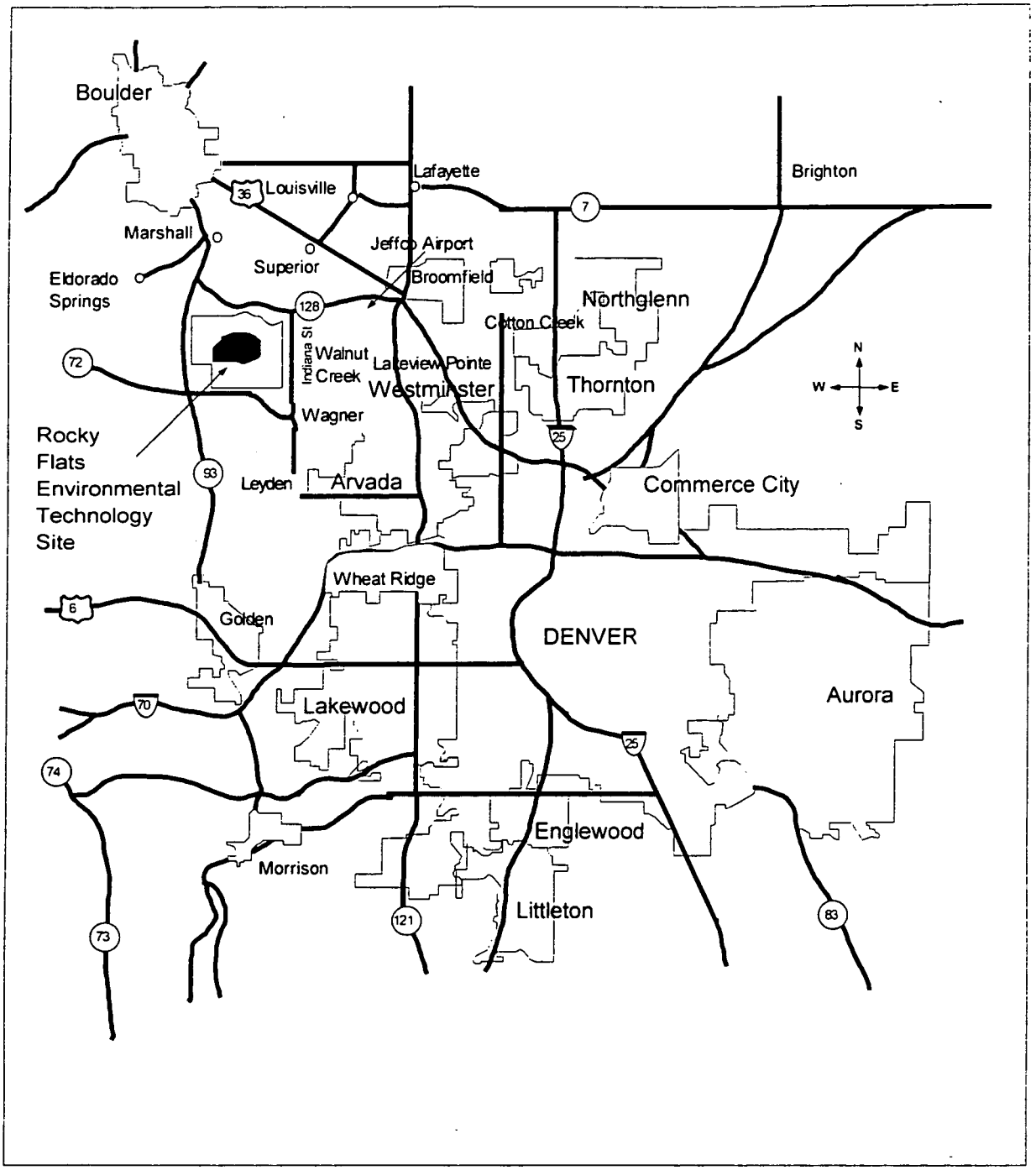

Figure 1-1. Area Map of the Rocky Flats Environmental Technology Site and Surrounding Communities

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Prior to 1989, the Site fabricated nuclear weapons components from plutonium, uranium (U), beryllium, and stainless steel. Production activities included metal fabrication and assembly, chemical recovery and purification of transuranic radionuclides, and related quality control functions. Plutonium weapons operations were curtailed at the Site in 1989 due to safety concerns, and in February 1992, the Site's weapons production mission was discontinued. Figure 1-2 shows the overall Site layout; former production areas are clustered in a central Industrial Area, which is surrounded by support facilities and vacant land.

The Site is now undergoing deactivation, decommissioning, and cleanup, and is moving toward final closure. Closure of the Site entails removal of nuclear material and waste products, which are being shipped to off-Site repositories and disposal facilities. Buildings will be removed and areas of contamination cleaned up. Clean fill dirt will be brought in from off Site to cap remaining building foundations and structures. The Site is expected to be dedicated to open space use following closure.

Between 1989 and 1995, resuspension of actinide containing soils and transport through the air pathway occurred primarily due to natural processes, such as wind erosion. Remediation of contaminated soils and waste disposal areas at the Site and building decontamination and decommissioning (D&D) activities began in 1995. Such activities disturb contaminated soils or contamination on building or equipment surfaces, and result in additional airborne particulates. Future resuspension of actinide containing material will occur due to both natural and anthropogenic activities.

The most significant soil contamination areas contributing to airborne actinides at the Site are the 903 Pad and the adjacent "lip" area. During the 1950s and 1960s, the 903 Pad was contaminated with plutonium-laden cutting oil that leaked from metal drums into the soil beneath the drums. Removal of the drums in the late 1960s and associated cleanup activities resulted in dispersion of contaminated soil to the east and south of the 903 Pad. The storage pad was covered with asphalt in 1969, and is no longer a source of resuspendable actinides. However, the initial spread of the contaminated soil prior to the installation of the asphalt pad resulted in a plume of actinides in the surface soils extending to the east and southeast from the 903 Pad itself.

Other spills and releases have resulted in smaller areas at the Site where the surface soils are contaminated with different actinides (such as uranium isotopes). In addition, naturally occurring uranium deposits may also result in areas of elevated surface soil uranium concentrations. Actinide concentrations in surface deposits at the Site have been sampled and mapped, and the resulting data form the basis of the actinide emission estimates developed as part of the work reported here.

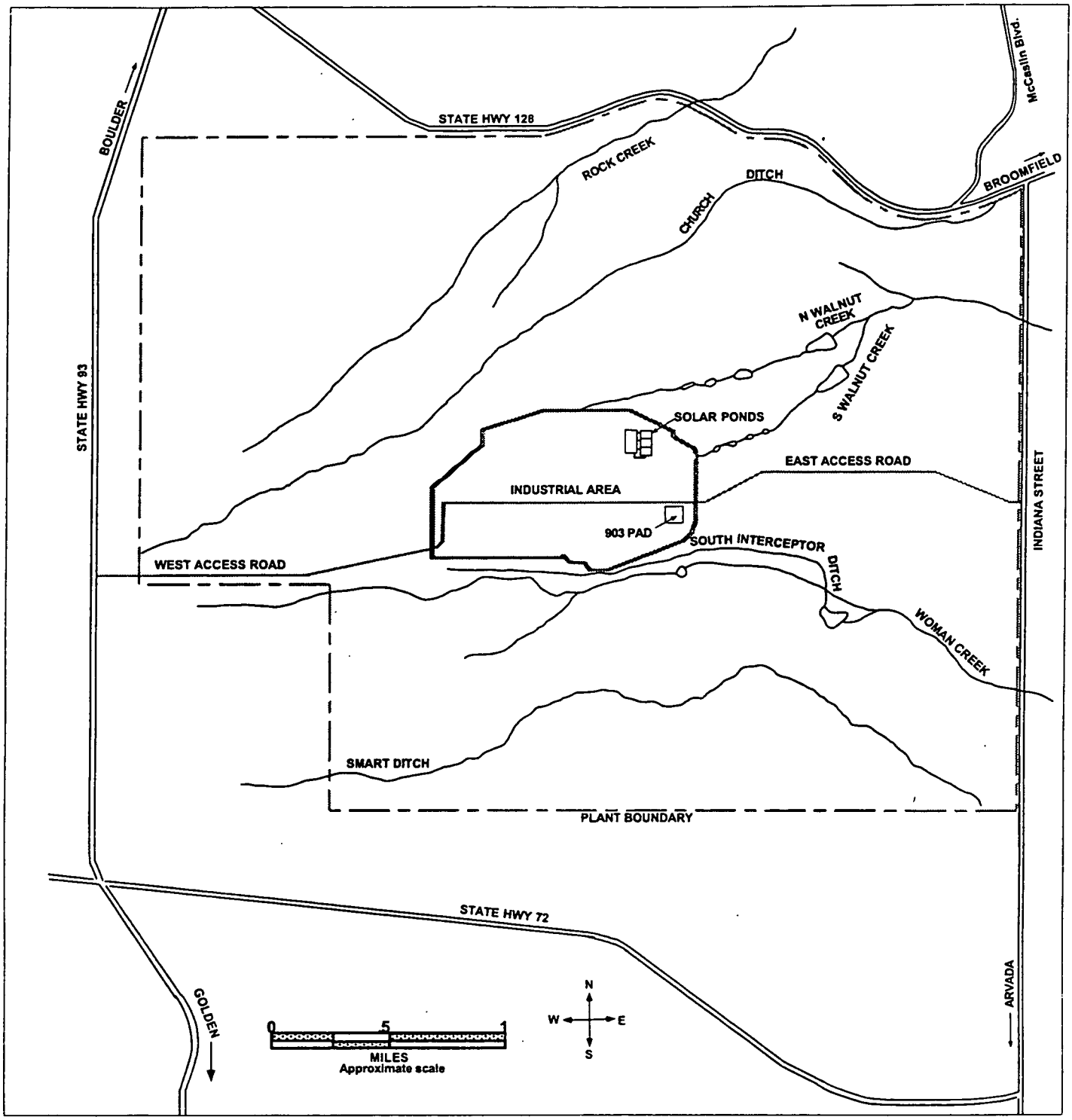

Figure 1-2. Rocky Flats Environmental Technology Site Location Map

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1.2 Overview of FY99 Air Pathway Investigations

In many respects, the FY00 air pathway work represents a continuation and refinement of the work performed during FY99. As a result, the scope and results of the FY99 work will be briefly reviewed here to put the FY00 scope in context.

The FY99 air pathway report was distributed to interested members of the public and the technical community, and is available on the RFETS web site (http://167.253.8.4/eddie/Data/Reports/AirTransport_DepositionActinidesFY99.pdf). Comments were received from two members of the public and from a peer reviewer engaged by Kaiser-Hill. The comments and peer review provided several useful suggestions that have been incorporated in the FY00 work or that will be addressed in planned FY01 investigations. These public and peer review comments are summarized and responded to in Appendix A to this report.

1.2.1 FY99 Emission Estimation

Actinide resuspension due to natural phenomena at the Site is episodic in nature and influenced primarily by meteorological variables (wind speed and rainfall); particle and soil properties (moisture level, and particle size and density); and surface characteristics (density and type of vegetative growth, and snow cover). Given the density of vegetation growing on the contaminated soil areas of the Site, a primary source of contaminated soil resuspension is likely to be the dust-laden vegetation and litter, with less potential for direct resuspension from soil surfaces except during high wind events or after disturbances.

Past wind tunnel experiments on Site relate dust resuspension to ambient wind speed and currently provide the best method for estimating emissions. Site wind tunnel data indicate dust resuspension varies with wind speed raised to the third power.

An equation was derived relating hourly particulate and actinide emissions to wind speed, underlying surface-soil contamination levels, and the presence or absence of snow cover. This equation was used to calculate hourly emissions due to natural resuspension mechanisms for five actinides for a full year. The calculated emissions were used as input to dispersion and deposition simulations.

In addition, calculation methods were identified for a variety of anthropogenic emission mechanisms, such as excavation, traffic, maintenance of storage piles, etc. These methods were used in conjunction with the natural resuspension equation identified above to calculate actinide emissions from specific remediation, D&D, and fire-related scenarios in FY00.

1.2.2 FY99 Dispersion and Deposition Modeling

In parallel with the emission estimation activities, a model was developed to simulate dispersion and deposition of actinides for a variety of emission events or scenarios. An annual scenario was modeled representing the "chronic" resuspension of actinides. Airborne actinide concentrations due to these ongoing emissions were estimated at a variety of locations on and around the Site. Annual deposition of actinides that have become airborne due to chronic resuspension mechanisms was also estimated at locations on and around the Site.

Maximum off-Site actinide concentrations due to natural resuspension mechanisms were predicted to occur along the Site's eastern fenceline. This location was anticipated, given the predominant westerly winds at the Site. Similarly, the annual predicted Pu-239/240 and Am-241 deposition contours were found to extend toward the east-southeast from the eastern edge of the Industrial Area. The patterns of annual deposition for the uranium isotopes were variable because of the differing locations of the sources (areas of higher surface soil concentrations).

1.2.3 FY99 Comparison and Sensitivity Analyses

Air sampling data for Pu-239/240 for the 1996 calendar year were available for comparison with model results (1996 meteorological data were used for the modeling). Model-predicted concentrations were found to be higher, by one to two orders of magnitude, than the measured concentrations. A number of potential factors were identified. Several of these factors were used to revise the modeling methodology for FY00 to decrease potential overprediction.

Three sensitivity analyses were also performed to examine: 1) the inclusion of an additional source at the background or fallout level of Pu-239/240, 2) the performance of a general resuspension factor previously developed for the Site, and 3) the effect of plume depletion on predicted concentrations. The first analysis showed that inclusion of an additional source at background levels would not substantially increase predicted actinide concentrations.

The second analysis showed that the Sitewide resuspension factor developed previously produces results that match measured actinide concentrations fairly well (within the same order of magnitude). This is not surprising because the resuspension factor was developed from on-Site sampling data collected just to the east of the 903 Pad. However, the general resuspension factor can only be used to calculate annual average actinide values, whereas the method developed in this study can be used to vary emissions and impacts on an hourly basis.

The third analysis showed that removing the mass of particulate that is deposited to ground or surface waters from the airborne particulate plume would decrease predicted air concentrations by 20 to 26 percent. The deposited particulate fraction, which was "double counted" in the FY99 study, was taken into account in the FY00 work, resulting in improved model predictions.

Information was also presented on a related study that examined the strength of the correlation between meteorological variables and measured actinide air concentrations on Site. Measured Pu-239/240 concentrations to the east of the 903 Pad were shown to be strongly correlated with the occurrence of strong, westerly winds (as expected). The amount of precipitation, on the other hand, did not directly correlate with measured concentrations.

1.3 FY00 Air Pathway Work Scope

The focus of the FY00 work was to use the model and emission estimating technique developed in FY99 to look at the impact of specific activities on airborne actinide concentration/dose and actinide deposition. As Site closure proceeds, remediation projects and building D&D will result in airborne actinide emissions as contaminated soils or material are disturbed. One goal of the FY00 modeling was to estimate reasonable upper bounds on the amount of airborne actinides that could result from these types of activities.

Other situations that could result in elevated actinide levels in air include wildfires, post-fire resuspension, and high wind events. The FY00 work also estimated emissions and dispersion from these types of activities, again with the goal of generating reasonable upper bound values.

Finally, the FY00 work estimated airborne actinide levels and deposition that would result from normal resuspension processes operating during post-closure, assuming an absence of significant soil disturbance (consistent with open space use). The potential effect of periodic disturbances on resuspension was also reviewed. An additional area of investigation was to see if gradual outward migration of very small amounts of actinides over long periods of time would have measurable effects on population exposure.

1.4 Integration of Air Pathway Results with Other Investigations

As discussed previously, the FY00 work was designed to investigate emission scenarios and events that may be of interest with regard to actinide migration during and after Site closure. The scenarios were not intended to provide definitive data regarding specific remediation or D&D projects because many pertinent details of those actions are still undergoing review and refinement. Instead, the scenario modeling was intended to

provide reasonable upper bounds for the expected impacts of closure activities and post-closure Site configurations.

The air pathway has not proven to be a threat to public health over the past decade, and emissions from vegetated areas with surface soil contamination do not seem to be of concern based on the FY99 air pathway investigations. Understanding and demonstrating the mechanisms for resuspension are necessary to eliminate this natural pathway from consideration in future cleanup decisions, or to identify circumstances where the pathway may become important.

Information about the air pathway and the "what-if" scenarios reported here will be integrated with information developed about other pathways of actinide migration in several future reports. In addition, the information developed through the actinide migration evaluation project will provide input to a number of documents that implement Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) requirements at the Site.

In addition to direct uses in the actinide migration study, the model developed in the FY99 work and refined in FY00 will be used in conjunction with other models (such as CAP88) for air regulatory compliance planning associated with proposed cleanup alternatives at the Site. For example, the ISCST3 model can be used to show comparative impact levels for various scenarios and control techniques. It is expected that additional modeling will be performed using the techniques outlined here as remediation or D&D projects at the Site proceed into the detailed planning phase and specific decisions are made regarding alternative strategies.

The FY99 air pathway investigations and the comments received on that work highlighted some important data gaps that may affect the accuracy and precision of the model estimates. As a result, additional investigations have been planned for implementation in FY00 or FY01, as outlined below.

- **Wind tunnel investigation of resuspension and post-fire recovery:** During the past two years, the Site has planned and evaluated a program of annual prescribed burns to reduce the buildup of flammable litter, restore native grasses, and control noxious weeds in portions of the Site. Several prescribed burns were planned for the Spring of 2000 and Kaiser-Hill developed a wind tunnel investigation in conjunction with those burns. The purpose of the wind tunnel study was to measure resuspension of soil and ash immediately following a burn and at intervals after the burn to determine how the resuspension rates varied from those measured over unburned, undisturbed areas of the Site. The post-burn sequence of wind tunnel tests was designed to investigate the time period over which resuspension rates would recover to pre-burn conditions.

Because of delays due to public communication issues and the timing of spring precipitation and wind events, the Site was unable to conduct a full-scale prescribed burn in 2000. However, a 50-acre test burn was conducted in early April. Wind tunnels tests were conducted over the burned area and paired tests were conducted in an adjacent, unburned area immediate following the test burn. Additional tests were conducted over the burned area in early May and late June. The June series also gathered additional data on resuspension from an adjacent, unburned plot for comparison.

Midwest Research Institute (MRI) performed the wind tunnel tests, using the same wind tunnel configuration that was used in a 1993 investigation at the Site (EG&G, 1994). The data from the 1993 MRI study formed the basis for the chronic, natural resuspension emission factor developed in the FY99 air pathway work (described in Section 2.2.1 of this report and in Radian, 1999). Consequently, the FY00 wind tunnel measurements should provide additional data with which to refine the emission estimating technique, as well as provide new information regarding post-fire recovery.

Because of a small grass fire caused by lightning at the Site in July 2000, additional wind tunnel investigations were also implemented. The grass fire burned an area with low levels of actinide contamination (approximately 2 pCi/g). The additional wind tunnel study gathered data on particle and actinide activity in different size fractions of resuspended material and in the underlying soil.

The wind tunnel data were not available for use in the FY00 air pathway modeling, although preliminary observations were factored into the development of the post-fire scenario (see Section 5.0 of this report). Wind tunnel data will be available in Fall 2000 and will be used to refine model estimates in FY01.

- **Roadway Dust Sampling:** One of the assumptions made in the FY99 air pathway investigation was that paved and unpaved roadways on Site were not sources of resuspendable actinides. This assumption was made because the roads in the vicinity of the 903 Pad, which may have been subject to surface contamination before the pad was covered with asphalt, were covered with clean dirt and road base brought in from off Site in the 1980s. This assumption was questioned by reviewers because no measurement data were available to confirm the assumption. Also, the 903 Pad and lip area continue to be a source of resuspendable actinides, although at much lower levels than occurred during the initial suspension events associated with the pad, and may contribute to recontamination of nearby road surfaces.

  If the roads in the vicinity of the 903 Pad contain measurable amounts of actinides in surface dust, the omission of this source from the modeling could lead to

inaccurate results. Traffic is the single largest source of particulate emissions on Site, and any actinides in dust on unpaved or paved road surfaces could result in airborne actinide emissions, as well as contribute to surface loading of actinides on nearby vegetation. Even small amounts of surface contamination on roads would be subject to frequent resuspension by traffic or wind, since disturbance by traffic serves to renew the erodible surface layer on unpaved roads.

As a result, direct measurement of actinide concentrations in road dust collected in the vicinity of the 903 Pad is planned for FY01. The results may be used to revise the air pathway modeling if the FY00 results and the results of the dust measurement program suggest that further modeling is warranted.

1.5 Contents of FY00 Air Pathway Report

As described previously, much of the FY00 work focused on modeling emissions and dispersion from several types of post-closure and closure-related activities that could result in airborne particulate and actinide emissions. Those investigations are reported as follows:

- **Section 2.0** describes the revised natural resuspension scenario. This scenario was a refinement of the scenario modeled in FY99. Appendix B presents information regarding modeling issues, as well as the results of the simulation.

- **Section 3.0** describes emission estimation and modeling of two remediation scenarios. One scenario looked at the proposed cleanup of the 903 Pad over a 1-year timeframe. The second scenario looked at the effects of a high wind event during the remediation. Appendices C1 and C2 present the technical details of the emission estimation and modeling, respectively.

- **Section 4.0** describes a simulated short-term release during D&D. Appendices D1 and D2 describe the details of the emission estimation and modeling, respectively.

- **Section 5.0** presents data for two sets of fire-related simulations. The first set of scenarios explored emissions and short-term impacts related to wildfire events in the east Buffer Zone, both pre- and post-closure. The second set of scenarios looked at emissions due to wind resuspension during a 1-year period following a wildfire. Appendix E1 describes the emission estimation methods for the fire and post-fire scenarios, while Appendix E2 discusses the modeling methods and results.

- **Section 6.0** looked at wind resuspension emissions from the Site following closure. The scenario was based on negotiated cleanup levels and assumed open space use. Appendix F presents the model results for this scenario.

- **Section 7.0** describes three separate investigations. The first investigation explored the contradictory effect of varying wind speeds on resuspension emissions and dispersion. The second investigation looked at the potential effect of periodic soil disturbances on emissions. This investigation quantified how occasional disturbances through excavation or traffic might alter the conclusions of the post-closure scenario described in Section 6.0 (which assumed no soil disturbance, consistent with open space use). Finally, this section describes several methods that were used to estimate possible long-term migration of actinides from the Site, such as might occur over a 1,000-year timeframe.

- **Section 8.0** summarizes the findings and recommendations of the report, as well as suggesting where data gaps may still exist that would affect the air transport pathway calculations.

2.0 SCENARIO 1: REVISED RESUSPENSION MODELING

Scenario 1 is a revision of the resuspension modeling that was conducted for FY99 (see Radian, 1999). The modeling was revised with updated source information and several enhanced modeling assumptions. Updated source information was obtained from revised soil maps for Pu-239/240 and Am-241. Enhanced modeling assumptions included the use of more appropriate particle densities and mean particle diameters for plume depletion and deposition. Additionally, optimized area source options within the ISCST3 model and simultaneous modeling of concentration and deposition were used to improve model run time. Model receptors were revised from FY99 to include additional specific points of interest such as ambient samplers and waterways. This section describes the FY00 modeling scenario, the specific emission estimation and modeling approaches used for FY00, and the model results for FY00.

2.1 Scenario Description

Actinides occur in Site surface soils due to past spills and releases, as well as the natural distribution of uranium in some area soils. As described in Section 1.1, the most extensive release occurred from an area known as the 903 Pad. Other smaller releases of uranium, plutonium, and americium isotopes have resulted in isolated areas with surface soil actinide levels above background concentrations at other locations on Site.

Resuspension of actinide-containing soils is an ongoing phenomenon that is episodic in nature and influenced primarily by meteorological variables (wind speed and rainfall); particle and soil properties (moisture level, and particle size and density); and surface characteristics (density and type of vegetative growth, and snow cover). Wind erosion of exposed soil surfaces, contaminated soil on vegetation surfaces, contaminated soil on litter, and decaying litter itself may all contribute to airborne actinides in the vicinity of the Site. Given the density of vegetation growing on contaminated soil on the Site, however, direct resuspension of actinides from exposed soil surfaces would occur primarily under very high wind speed conditions or following disturbances.

The goal of the resuspension modeling was to estimate the dispersion and deposition of actinides from the resuspension of contaminated soil at the Site, focusing on chronic, natural resuspension mechanisms that would be ongoing with or without anthropogenic activity.

2.2 Emission Estimation

This section describes the basic emission estimation method for wind erosion of contaminated soil and vegetation that was developed in FY99, as well revisions that were made for the FY00 modeling.

2.2.1 Resuspension Emissions

A significant amount of research in particle and actinide resuspension has occurred over the years (see Radian, 1999). This research emphasizes the need to customize any approach to the particular location of interest. The unique meteorological, soil, and surface characteristics must be taken into account to produce a reliable emission estimation approach for a given area.

Past wind tunnel experiments on Site relate dust resuspension to ambient wind speed and currently provide the best method for estimating emissions due to wind erosion of undisturbed areas of the Site. In FY99, a method was developed to estimate emissions of actinides from vegetated surfaces based on wind tunnel data taken in Operable Unit 3 (OU3, located just east of Indiana Street) in June 1993 (EG&G, 1994). Although the number of data points in the data set was extremely limited, the 1993 OU3 wind tunnel data set was considered the most representative of current conditions on Site. Wind speed was plotted against the measured flux of resuspended dust. Applying a power fit to the data produced the following expression:

$$E = 2 \times 10^{-9} (U^{3.014})$$

where:

E is the total particulate emission rate in grams per square meter per second ($g/m^2/s$); and U is the 10-meter (m) wind speed in meters per second (m/s).

In the selected approach, estimated emission rates were set equal to zero if snow cover was present, based on 1996 meteorological data. Meteorological data for 1996 were used in the study because the 1996 data showed fewer missing values than 1997 or 1998 for parameters needed for the emission estimation and modeling.

The estimates of particle resuspension provided the basis for predicting airborne radioactivity concentrations (i.e., picocuries per cubic meter of air [pCi/m^3]), airborne effective dose equivalent (EDE, in millirem [mrem]), and activity deposition on ground or water surfaces (in picocuries per square meter per year [$pCi/m^2/yr$]). The distribution of actinides in Site surface soils has been determined in units of picocuries per gram of soil (pCi/g), as discussed below, and the particulate (resuspension) emissions from each particular Site location were combined with this information to yield actinide emissions in picocuries per square meter per second [$pCi/m^2/s$].

Soil isopleth maps showing the estimated distribution of actinide activity in surface soils have been developed previously from soil sampling conducted on Site. These maps provide the spatial "source strength" that forms the basis for the emission estimates developed in this task.

2.2.2 Emission Estimation Revisions for FY00

Revisions were made to resuspension emission estimates for the Site based on revised soil activity contours (isopleths) for Pu-239/240 and Am-241. The revised isopleth patterns were also used to create the area sources that represent Pu-239/240 and Am-241 emissions within the ISCST3 model (discussed in Section 2.3).

Radian obtained revised soil activity (in pCi/g) contour maps from Rocky Mountain Remediation Services, L.L.C. (RMRS, 2000). These maps reflect a revised contouring method (Kriging) that was applied to the Site soil sampling database. Each activity contour was electronically digitized and a routine within AutoCAD Map® (Release 2.0) software was used to reduce each contour to a series of points. The points defined a multi-sided polygon approximating each contour's shape for emission estimation and modeling purposes.

Landuse maps for the Site were used to determine the areas within each contour that consist of material that would not be eroded, specifically the paved areas and buildings within the Industrial Area. These nonerodible areas were excluded as areas of emission. Activity contours for the uranium isotopes were not revised for FY00, and therefore the emissions and area source representations for uranium that were used for the FY99 modeling were also used for the FY00 modeling. Because the uranium area sources were so sparse, all sources for uranium were included in the model, whether located on erodible or nonerodible surfaces.

2.3 Modeling Methods

Predicting the impact of various emission events at the Site requires the use of a dispersion and deposition model to simulate the transport of pollutants from the locations of emission to other locations of interest (termed receptors). The air pathway work performed in FY99 reviewed a variety of model formulations in choosing the most appropriate model for this study. The FY99 work concluded that ISCST3, a Gaussian plume formulation, would be the best model for the application. ISCST3 is described in detail in the *User's Guide for the Industrial Source Complex (ISC3) Dispersion Models, Volumes I and II* (EPA, 1995a) and is also described briefly in the FY99 air pathway report (Radian, 1999). Appendix B to this report gives an overview of dispersion/deposition models in general and Gaussian models in particular.

2.3.1 Model Input Data

The ISCST3 model requires the input of detailed source characteristics, meteorological data, dispersion modeling option selections, and desired locations of model predictions (i.e., receptors). The inputs that were used for both the FY99 and FY00 actinide migration study modeling are described below.

Model Options

The ISCST3 model was used to estimate the transport of airborne actinides from source areas at the Site to the fenceline of the Site (*dispersion*) and their removal from the air to soil or water surfaces on or surrounding the Site (*deposition*). Particulates are brought down to the surface through the combined processes of turbulent diffusion and gravitational settling. Once near the surface, they may be removed from the atmosphere and deposited on the surface. Deposition, and the manner in which ISCST3 simulates it, are described more fully in Appendix B.

As in FY99, airborne radioactivity was estimated in units of picocuries per cubic meter of air (pCi/m^3), while deposition on ground or water surfaces was estimated in units of picocuries per square meter per year ($pCi/m^2/yr$). From the estimated airborne concentrations, airborne EDE in mrem was computed by applying conversion factors (described below). Rural dispersion parameters were used for all model runs. Wet deposition was not modeled because the contribution to total deposition by wet removal mechanisms was assumed to be insignificant (EPA, 1999).

Meteorological Data

An ISCST3 meteorological input file was created using the EPA Meteorological Processor for Regulatory Models (MPRM) and was subsequently used for the FY99 modeling and for many of the FY00 scenarios, including Scenario 1. Surface meteorological parameters that were measured at the Site in 1996 were combined with concurrent upper-air and cloud cover data from the National Weather Service (NWS) station in Denver using MPRM. The output from MPRM was an hourly meteorological input file that could be used for both concentration and deposition modeling with the ISCST3 model. The 1996 meteorological data file was described more fully in the FY99 air pathway report (Radian, 1999).

Figure 2-1 illustrates the joint frequency distribution of wind direction and wind speed (wind rose) for the 1996 meteorological input file.

2.3.2 Model Inputs Revised for FY00

This section describes model input data that were changed from the scenario that was modeled for the FY99 air pathway report.

Modeling Receptors

Modeling receptors were revised for FY00 to include specific points of interest such as ambient samplers and waterways, and to concentrate receptors in the areas of expected maximum impacts. The base receptor grid for FY00 was a Cartesian grid with 200-m

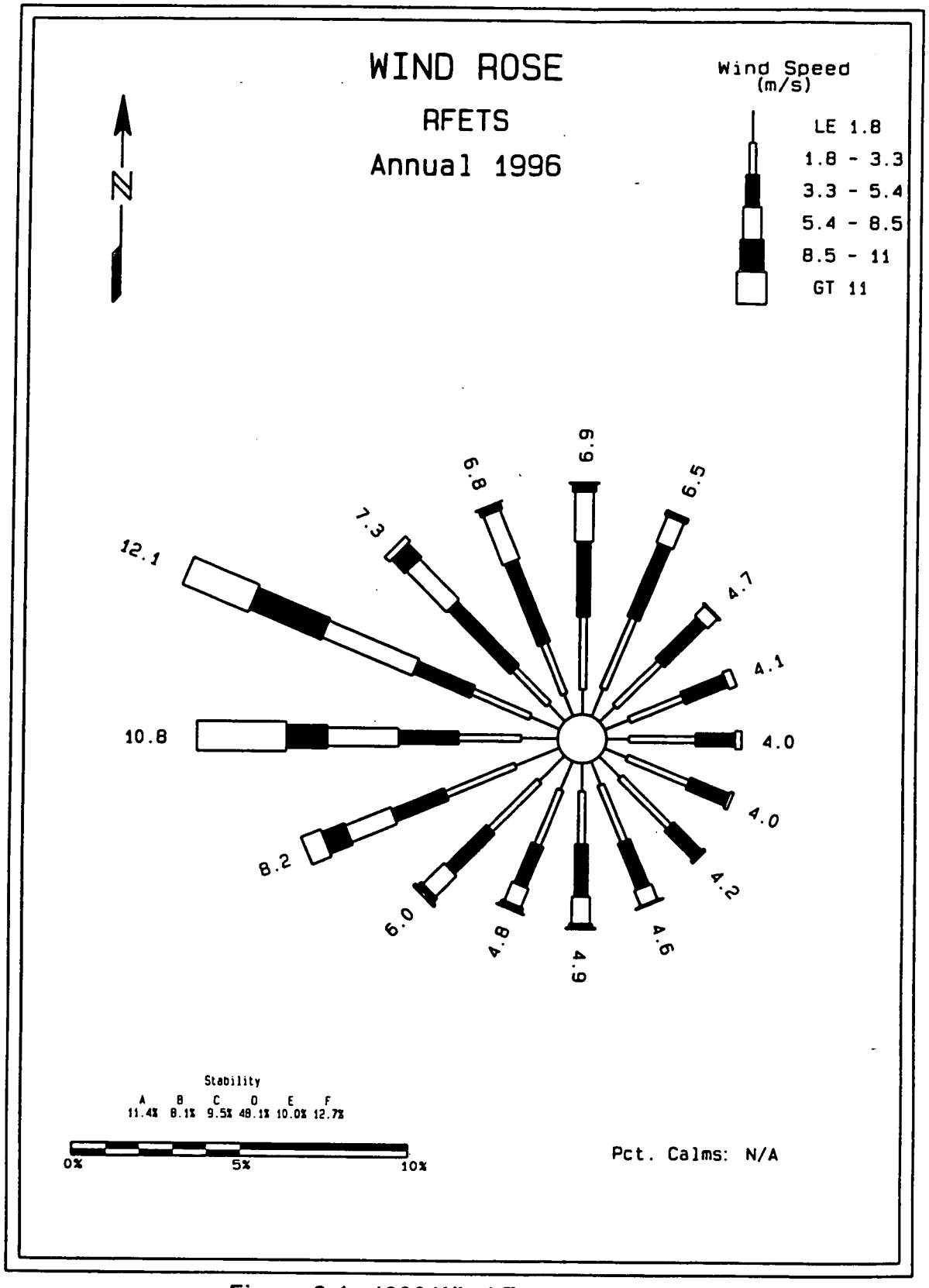

Figure 2-1. 1996 Wind Frequency Distribution

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receptor spacing that encompassed the Site and extended approximately 400 to 500 m beyond the Site boundary in selected directions. The grid represented a reduction in the number of receptors from the FY99 grid in that receptors extended beyond the Site boundary only in the predominant downwind directions. Fenceline receptors were reduced from the 100-m spacing that was used for FY99 to 200-m spacing for FY00, with the exception of the eastern fenceline, where 100-m spacing was retained. Also added as discrete receptors for FY00 modeling were the eight residential or business locations that are used for modeling conducted annually to demonstrate compliance with Title 40 of the Code of Federal Regulations (CFR), Part 61, Subpart H, and receptors for each of the Radioactive Ambient Air Monitoring Program (RAAMP) samplers at the Site. Receptors were also placed at 200-m spacing along the major waterways at the Site, including Walnut Creek, Woman Creek, and the South Interceptor Ditch.

While the FY99 modeling presented estimated deposition impacts on a grid that covered the entire Site and presented concentration impacts only at the Site fenceline, the FY00 modeling made use of a common grid for both concentration and deposition. Figure 2-2 shows the receptor grid that was used for FY00 modeling.

Source Data

Spatial Definition of Source Areas—The goal of the Scenario 1 modeling was to estimate the dispersion and deposition of actinide activity from the resuspension of soil at the Site, focusing on chronic, natural resuspension mechanisms that would be ongoing with or without anthropogenic activity. As described in Section 2.2.2, revisions were made to the spatial patterns of resuspension emissions at the Site based on revised soil activity contours (isopleths) for Pu-239/240 and Am-241. The revised isopleth patterns were used to generate source input data for Pu-239/240 and Am-241 for the ISCST3 model. Uranium area sources remained the same as those in FY99. Activity contours for each actinide were modeled as area sources, with release heights at the surface. Figures 2-3 through 2-7 present the digitized contours for each of the five actinides that were input to the model as area sources.

Definition of Source Inputs for Deposition—To account for deposition, the ISCST3 model requires that particle size categories be defined for each source. Associated with each particle size category is a mass (or actinide activity) fraction, a particle density (in grams per cubic centimeter [g/cm^3]), and a particle diameter. The particle mass fraction and actinide activity fraction data are important inputs to the deposition modeling: the particle density and diameter affect gravitational settling, with larger and more dense particles depositing closer to their area of origin than smaller or less dense particles.

As previously discussed, the main source area of resuspended actinides at the Site is the area surrounding the 903 Pad. The plutonium particles in the cutting oil that leaked at the

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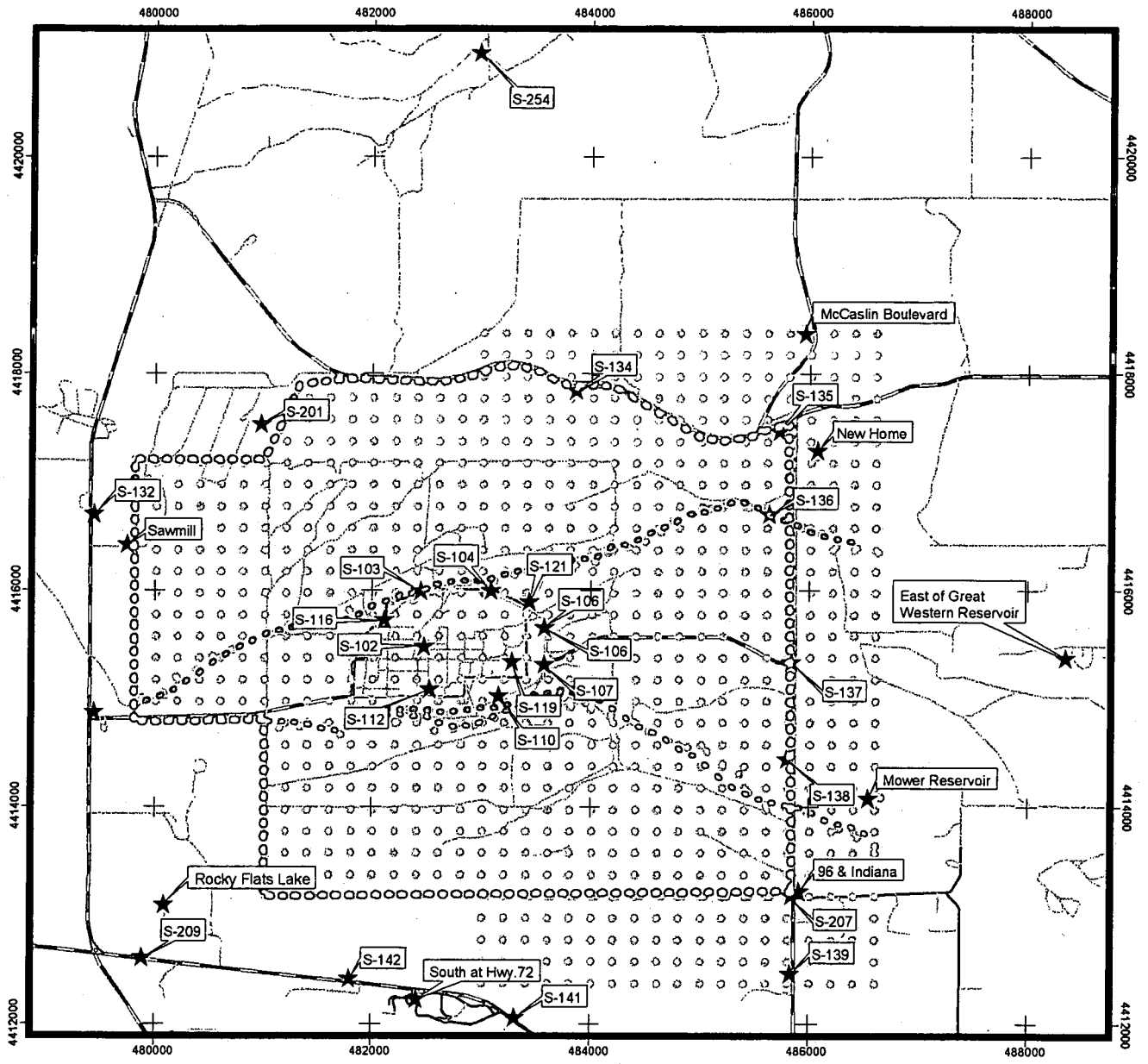

LEGEND

Modeling Receptor Type

- ☆ Discrete Receptor of Interest
- o Fenceline Receptor
- o Base Receptor

- o South Interceptor Ditch
- o Walnut Creek
- o Woman Creek

- Highways
- Major Roads
- Minor Roads and Streets

N

0.5 0 0.5 1 1.5 2 2.5 Kilometers

NOTE:
Coordinates reference
UTM Meters, Zone 13, NAD27

Figure 2-2. ISCST3 Receptor Grid

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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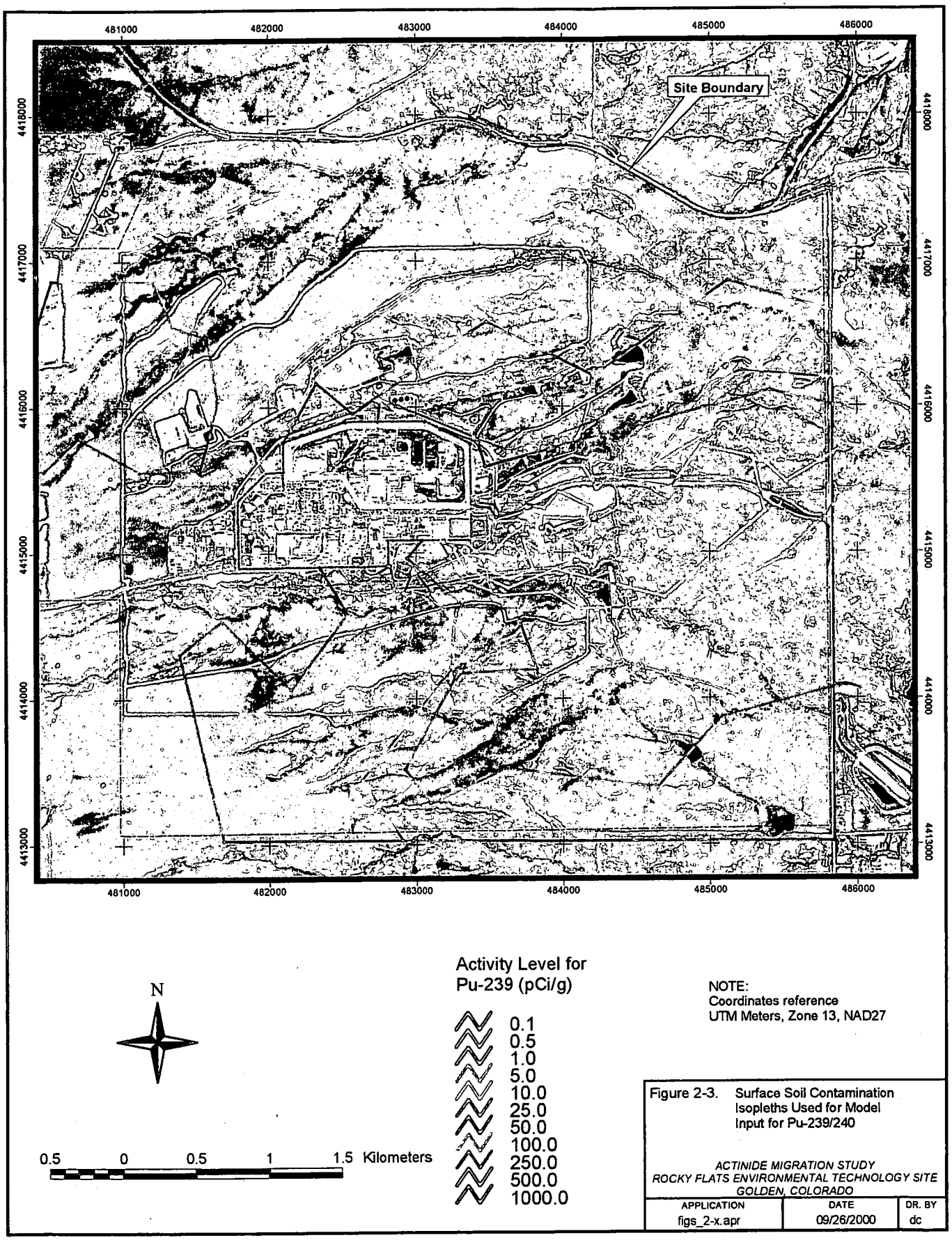

Figure 2-3. Surface Soil Contamination Isopleths Used for Model Input for Pu-239/240

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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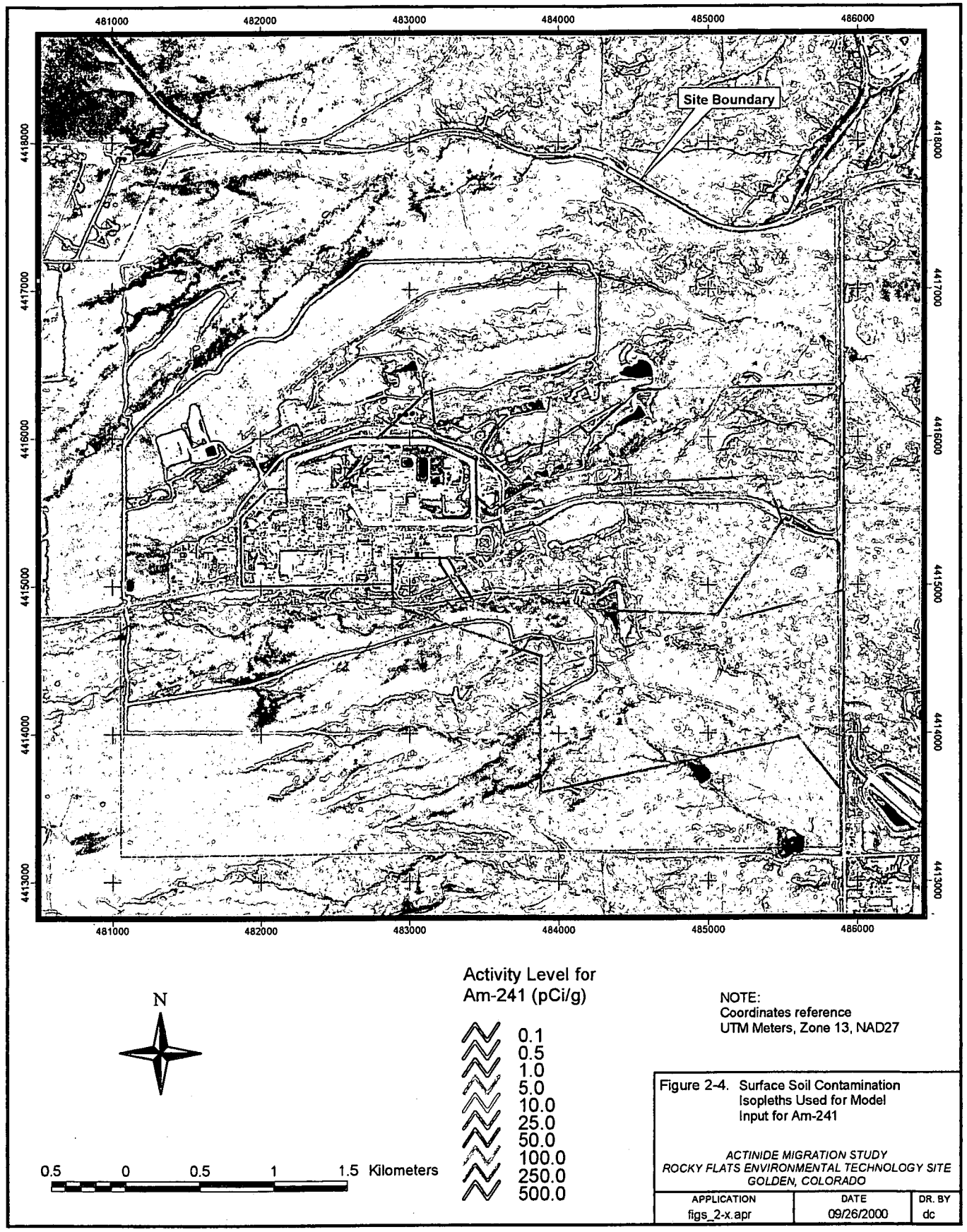

Figure 2-4. Surface Soil Contamination Isopleths Used for Model Input for Am-241

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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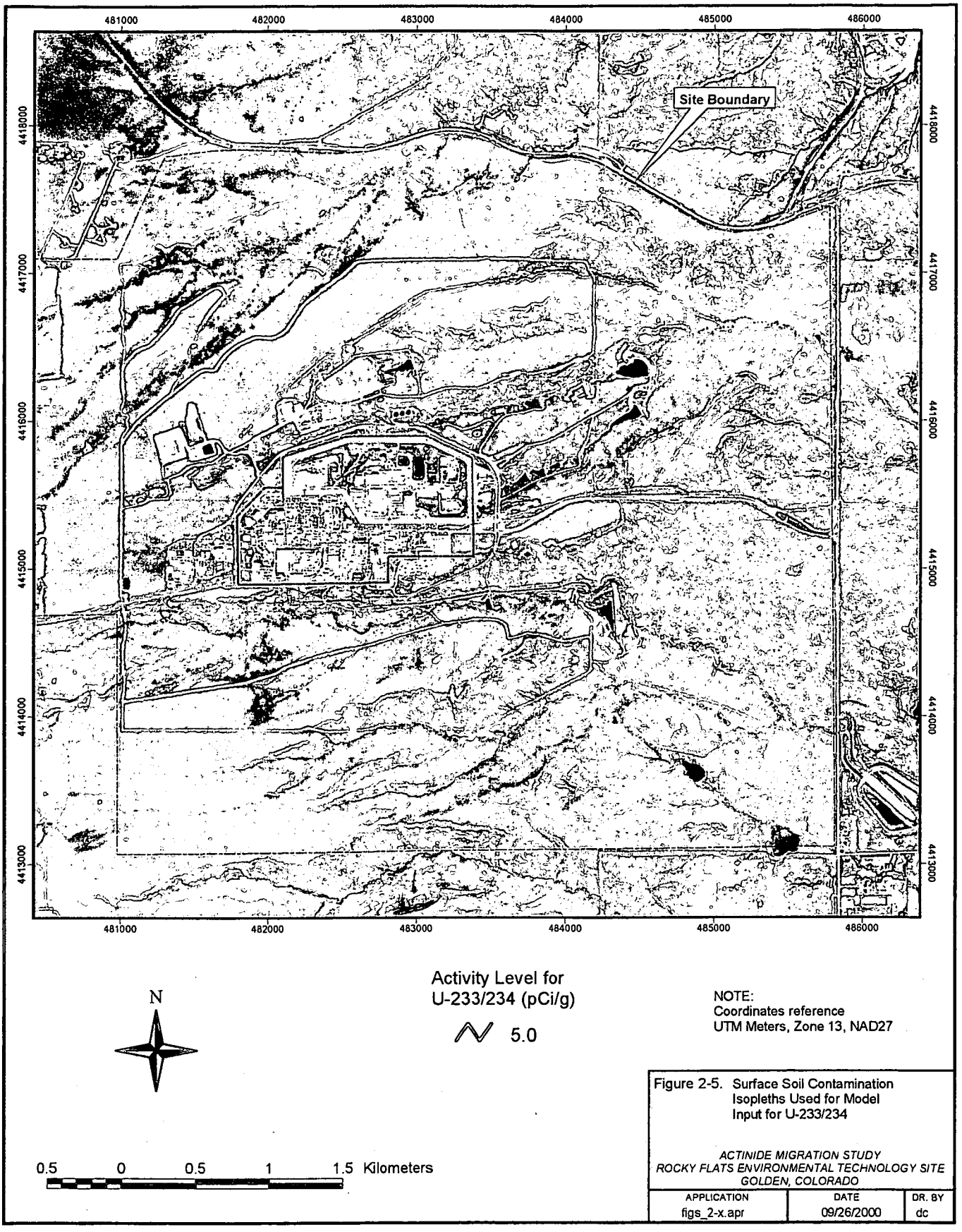

Figure 2-5. Surface Soil Contamination Isopleths Used for Model Input for U-233/234

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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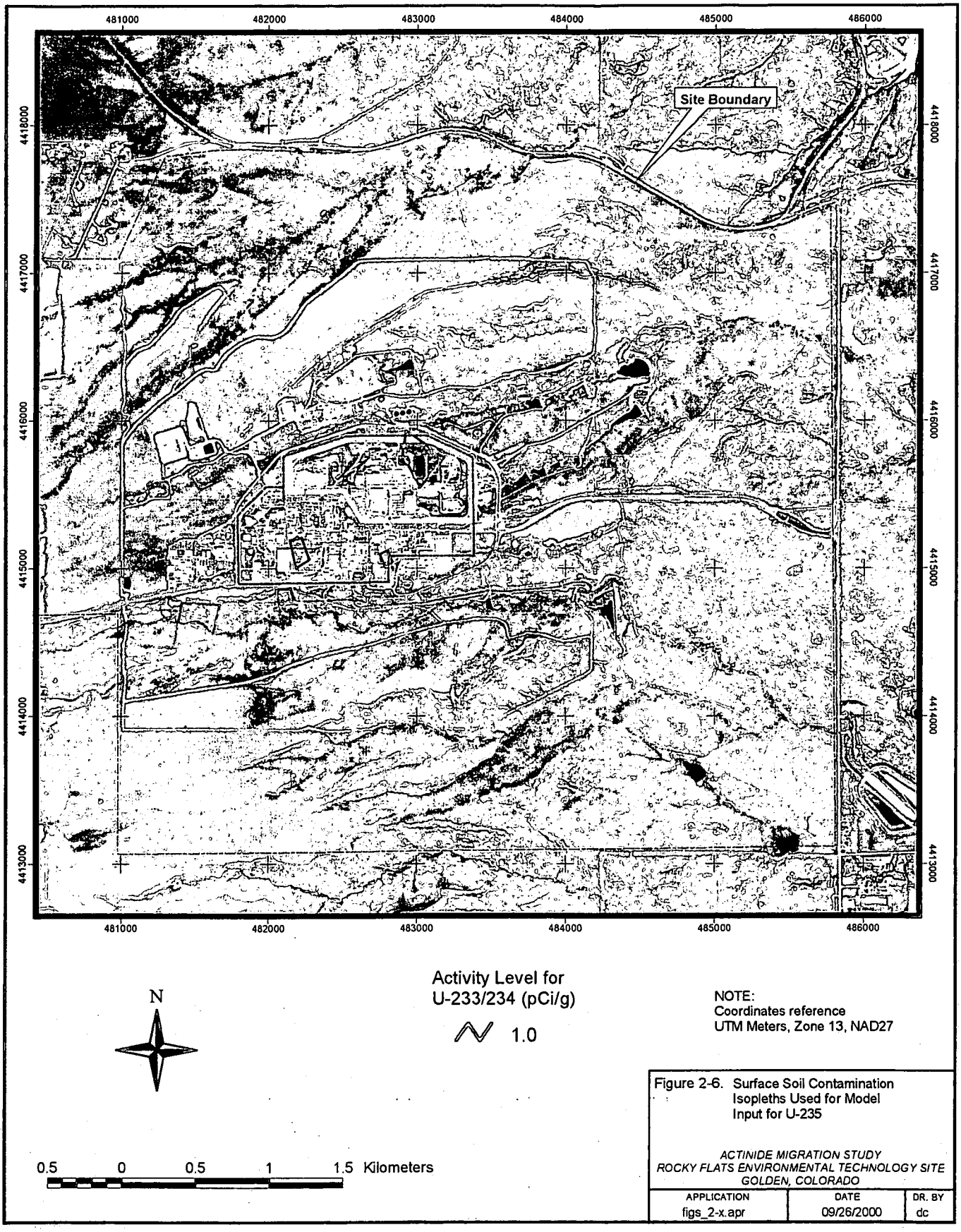

Figure 2-6. Surface Soil Contamination Isopleths Used for Model Input for U-235

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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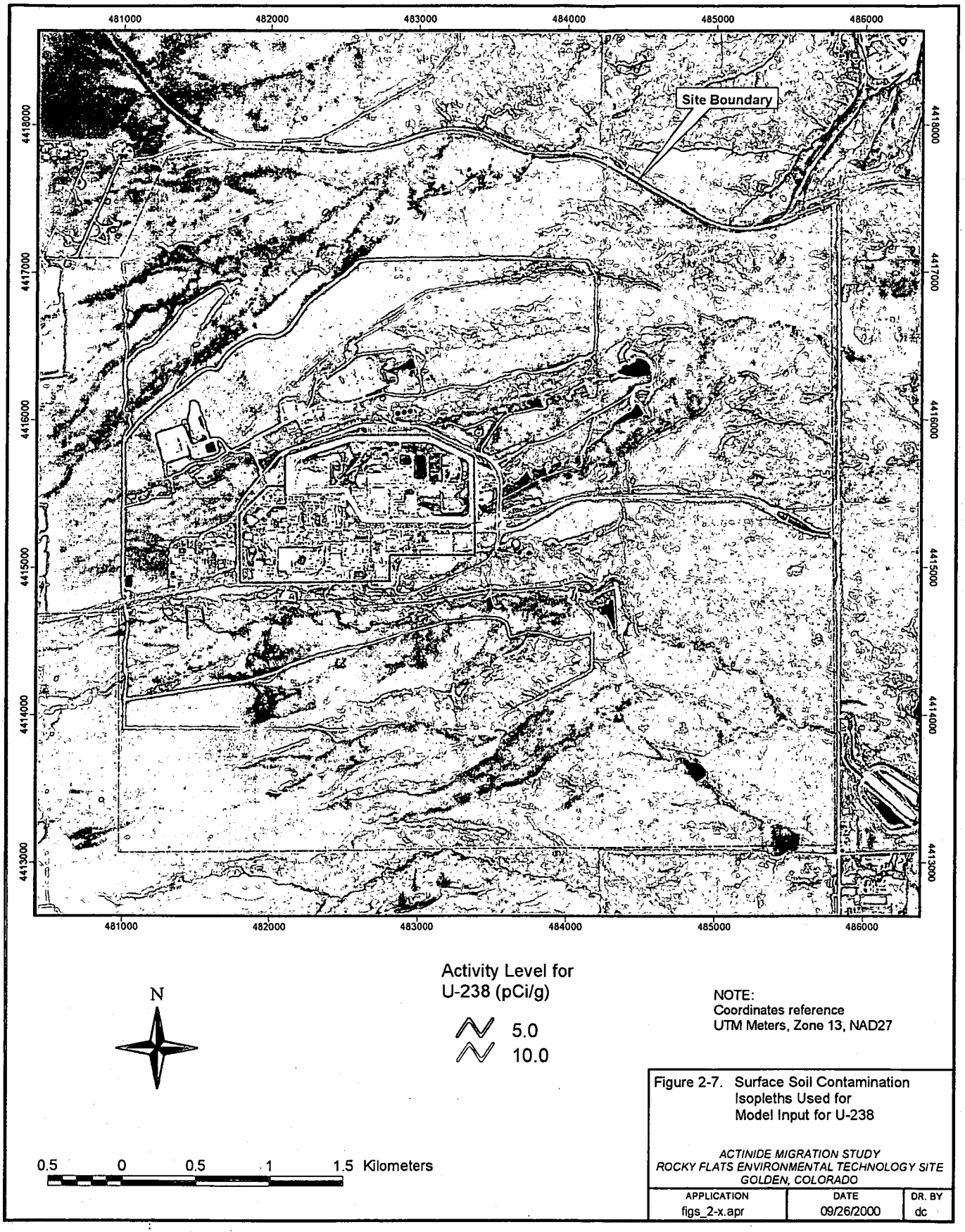

Figure 2-7. Surface Soil Contamination Isopleths Used for Model Input for U-238

ACTINIDE MIGRATION STUDY
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GOLDEN, COLORADO

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903 Pad were small (<3 micrometers [μm] diameter). Once in contact with the soil, however, the plutonium particles became attached to soil particles. Experimental data from the Site (Langer, 1986) and elsewhere (Shinn, 1999) indicate that most of the airborne plutonium activity is carried by the >15 μm diameter size fraction. Many of these larger particles are aggregates made up of varying size soil particles held together by binding agents (e.g., organic matter). Lesser amounts of plutonium may be attached to smaller, primary clay- and silt-sized particles. Because of its attachment affinity, the transport of plutonium is dependent on the soil or aggregate particle properties and not the properties of the individual plutonium particles.

Am-241 is associated with the 903 Pad area and other areas of Pu-239/240 contamination at the Site due to americium ingrowth into decaying weapons-grade plutonium (Am-241 is formed by radioactive decay of Pu-241 atoms). Consequently, Am-241 is expected to be distributed in the soil matrix in the same manner as Pu-239/240. Past research at the Site has shown that coarse particles (>15 μm) also carry most of the uranium activity in windblown dust (Langer, 1987). Therefore, the activity distribution among various particle size categories was assumed to be the same for each of the isotopes studied.

As in the FY99 modeling, particle size category bounds for the FY00 modeling were chosen based on the joint particle size/actinide activity data available (Langer, 1986). The particle data used for FY00 modeling are shown in Table 2-1. The data in Table 2-1 reflect certain refinements over the FY99 modeling such as the use of more appropriate particle densities, and use of a mass-mean diameter for the particle size category.

To arrive at the mean particle diameters shown in Table 2-1, the following equation was used (EPA, 1998):

$$D_{mean} = \left[0.25\left(D_1^3 + D_1^2 D_2 + D_1 D_2^2 + D_2^3\right)\right]^{0.333}$$

where:
D_{mean} is the mean particle diameter for the particle size category (μm);
D_1 is the lower bound cut of the particle size category (μm); and
D_2 is the upper bound cut of the particle size category (μm).

The particle size distribution actually is a function of wind speed. The higher the wind speed, the greater the fraction of larger particles. However, insufficient data are available to characterize a change in distribution with wind speed, so the distribution has been assumed constant across wind speeds.

To model the concentration and deposition of actinides due to wind resuspension, the activity fractions shown in Table 2-1 were input for the mass fractions for the three particle size categories.

Table 2-1. Particle Size Distribution Data Used for FY00 Dispersion Modeling

Particle Size Category	Lower-Upper Bound for Particle Size Category (μm)	Mean Diameter for Particle Size Category (μm)	Particle Density (g/cm^3)[a]	Plutonium Activity Fraction[b]
1	1-3	2.15	2.65	0.04
2	3-15	10.15	2.65	0.19
3	15-30	23.23	1.8	0.77

[a] Foster et al., 1985.
[b] Values at the measurement height of 1 meter (Langer, 1987).
Notes:
μm = micrometers
g/cm^3 = grams per cubic centimeter

Model Options

The use of default ISCST3 plume depletion and area source algorithms with the FY99 modeling resulted in excessive model run times because of the complexity of the Site source areas. To improve model run time for FY00, Radian used optimized area source and dry depletion algorithms that are available as options with the ISCST3 model. For area source modeling, the TOXICS option makes use of an alternative numerical integration technique that improves run time over the default algorithm. Area source modeling for FY00 included the option for dry plume depletion, and the AREADPLT option within ISCST3 allowed for further reductions in run time. The AREADPLT option makes use of a single "effective" depletion factor rather than the numerical integration used with the default ISCST3 depletion algorithm.

Plume depletion was used only for the estimation of actinide deposition in FY99 and not for estimation of concentration to avoid the excessive run times associated with the default depletion routines. For FY00 modeling, more realistic estimates of concentration were produced by accounting for plume depletion (plume depletion was also used for deposition estimates).

2.4 Modeling Results

This section discusses the results of the FY00 chronic, natural resuspension scenario. Maximum off-Site actinide concentrations due to chronic, natural resuspension mechanisms were estimated for five isotopes: Pu-239/240, Am-241, U-233/234, U-235, and U-238. Particulate concentrations were not calculated for this scenario because particulate concentrations due to natural resuspension of Site soils would represent only a small fraction of the particulate matter in the air over the Site at any given time. While certain actinide emissions can be localized to the Site, particulate matter is emitted by

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many sources in the region. Consequently, particulate matter concentrations estimated for this scenario would not represent useful information.

In addition to calculating airborne concentrations of actinides (in units of activity per unit volume of air, e.g., pCi/m^3), results have also been converted to EDE. EDE, measured in units of Sieverts or mrem, represents the amount of radiation energy absorbed per gram of tissue, weighted by its potential to do damage and the susceptibility for harm to different tissues in the human body.

Conversion from activity to EDE depends not only on the isotope and the type of radiation it emits, but also on assumptions about exposure pathways and scenarios. To simplify this conversion, we have used conversion factors from EPA air regulations that are based on standard assumptions about exposure pathways and scenarios. Regulation 40 CFR 61 contains requirements governing emissions of hazardous air pollutants from certain source types. DOE facilities such as RFETS are subject to the standards of Subpart H, which limits radionuclide emissions from the facility to those amounts that would result in an annual dose to the public of no more than 10 mrem. Appendix E to 40 CFR 61 gives a table (Table 2) of radionuclide concentration values (by isotope) that can be compared to measured radionuclide concentrations in air to demonstrate compliance with the Subpart H standard. If a person was exposed to air containing a given isotope at the concentration levels listed in Table 2 for a full year (under the standard exposure assumptions inherent in these values), they would receive a 10 mrem EDE. Therefore, the Table 2 concentration levels can be used to convert between radionuclide concentrations (in curies per cubic meter [Ci/m^3] or pCi/m^3) and EDE (in mrem) for annual scenarios.

For the isotopes of interest in this study, the concentration levels from Appendix E, Table 2 are:

- Am-241 1.9×10^{-3} pCi/m^3
- Pu-239/240 2.0×10^{-3} pCi/m^3
- U-233/234 $7.1/7.7 \times 10^{-3}$ (use 7.7) pCi/m^3
- U-235 7.1×10^{-3} pCi/m^3
- U-238 8.3×10^{-3} pCi/m^3

Each of these isotopic concentrations equates to a 10 mrem per year (mrem/yr) EDE rate for the purposes of this modeling study.

For modeling, emissions in units of activity per unit area per unit time ($pCi/m^2/s$) were input for a given isotope, and the concentration results (in units of pCi/m^3) were then converted to units of mrem. The conversion factor for each isotope used the previously listed concentration values, plus the appropriate conversions between Ci and pCi (a pCi is 10^{-12} Ci) and between a 10 mrem and 1 mrem level.

Summary of Predicted Concentrations and EDEs

The maximum annual on- and off-Site concentration estimates and corresponding EDEs for all the actinides that were modeled are summarized in Table 2-2.

Pu-239/240 Concentration and Deposition

The maximum annual concentration of Pu-239/240 due to chronic, natural resuspension was predicted to occur at a point approximately 250 m east of the 903 Pad. Figure B-4 in Appendix B shows an isopleth plot of the estimated annual concentration distribution of Pu-239/240 in units of pCi/m^3. As shown in Figure B-4, the highest concentration at the facility fenceline was estimated to occur along the eastern Site boundary with a magnitude of approximately 1.7×10^{-5} pCi/m^3.

Table 2-2. Results Summary—Pre-Closure Chronic Resuspension Scenario

Isotope	Maximum Estimated Annual Concentration (pCi/m^3)		Factor for Conversion of pCi/m^3 to mrem	Maximum Estimated Annual EDE (mrem)	
	On Site	Off Site		On Site	Off Site
Pu-239/240	4.6×10^{-4}	1.7×10^{-5}	5,000	2.3	0.09
Am-241	9.2×10^{-5}	2.1×10^{-6}	5,263	0.5	0.01
U-233/234	2.2×10^{-7}	3.6×10^{-9}	1,299	2.9×10^{-4}	4.7×10^{-6}
U-235	2.8×10^{-7}	8.5×10^{-10}	1,408	3.9×10^{-4}	1.2×10^{-6}
U-238	1.2×10^{-5}	8.4×10^{-9}	1,205	0.02	1.0×10^{-5}

Notes:
Am = americium
mrem = millirem
pCi/m^3 = picocuries per cubic meter
Pu = plutonium
U = uranium

Figure B-5 shows the distribution of estimated annual dry deposition of Pu-239/240 in $pCi/m^2/yr$. As would be expected, the annual maximum is centered just east of the 903 Pad. (Note: the isopleth levels that are plotted to show deposition contours in this report do not have any specific significance regarding impact levels or standards. They were selected for each actinide and scenario, as needed, to provide a useful visual presentation of the deposition results.)

Am-241 Concentration and Deposition

The maximum annual concentration of Am-241, like Pu-239/240, was predicted to occur approximately 250 m east of the 903 Pad. Figure B-6 shows isopleths of the estimated annual concentration distribution for Am-241. As shown in Figure B-6, the highest concentration at the facility fenceline was estimated to be approximately 2.1×10^{-6} pCi/m^3. This represents approximately 20% of the Pu-239/240 concentration that would occur in the same general location.

Figure B-7 shows the distribution of estimated annual dry deposition of Am-241 in pCi/m^2/yr. As with Pu-239/240, the estimated annual maximum is centered just east of the 903 Pad.

U-233/234 Concentration and Deposition

The annual concentration of U-233/234 due to chronic, natural resuspension was estimated to reach a maximum in the northeast portion of the Industrial Area near the Solar Ponds, just beyond the lone U-233/234 activity contour (source area) that was modeled (see Figure 2-5). Figure B-8 shows the estimated annual concentration distribution for U-233/234.

Figure B-9 shows the distribution of estimated annual dry deposition of U-233/234. The estimated annual maximum is centered near the northeast part of the Industrial Area.

U-235 Concentration and Deposition

Annual concentrations for U-235 due to chronic, natural resuspension were estimated to reach maximum levels in the northeast, southwest, and south-central portions of the Industrial Area, as shown in Figure B-10. The locations of the maximum estimated impacts correspond to the locations of the U-235 activity contours (source areas) shown previously in Figure 2-6.

Figure B-11 shows the distribution of estimated annual dry deposition of U-235 in pCi/m^2/yr. Most of the annual deposition of U-235 would be limited to the immediate vicinity of the Industrial Area.

U-238 Concentration and Deposition

Annual concentrations of U-238 due to chronic, natural resuspension were estimated to reach a maximum in the southwest portion of the Industrial Area and to the south and southwest of the Industrial Area proper. The maximum impacts were estimated to occur near the activity contours (source areas) for U-238 shown in Figure 2-7 (source areas). Figure B-12 shows the estimated annual concentration distribution for U-238.

Figure B-13 shows the distribution of estimated annual dry deposition of U-238 in $pCi/m^2/yr$. The maximum estimated deposition is centered near the southwest part of the Industrial Area.

2.5 Discussion

The results of the chronic, natural resuspension scenario show similar patterns to those seen in the FY99 modeling. As anticipated, maximum concentrations and deposition of Pu-239/240 and Am-241 were predicted to occur just to the east of the 903 Pad area, in the direction that high winds would be expected to spread contamination (see Figure 2-1). Locations of maximum concentrations and deposition of other actinides reflect a combined influence of prevailing high wind direction and the source origins of those actinides in surface soil at the Site.

2.5.1 Effect of Deposition on Environmental Distribution of Surface Soil Contamination

The overall deposition patterns of actinides produced by the Scenario 1 modeling appear similar to the existing distribution of actinides in Site surface soils (i.e., the source areas from which resuspension occurs). The present surface soil contamination patterns of Pu-239/240 and Am-241 are largely the result of windblown suspension and subsequent deposition of the soil that was contaminated by the leaking drums at the 903 Pad, with some additional spread due to surface runoff from the contaminated area. Deposition patterns from the Scenario 1 modeling for these actinides strongly reflect the initial source area patterns, as well as the annual distribution of higher speed winds at the Site (see Figure 2-1).

The distribution of high winds is relatively more important than the overall wind distribution for resuspension and deposition because increased volumes of soil are suspended at higher wind speeds. In addition, suspension occurs more readily from recently disturbed soil, so the particular wind speeds and directions coincident with disturbances during the initial 903 Pad remediation sequence would have a strong influence on the resulting surface soil contamination patterns. Resuspension and deposition from undisturbed, vegetated surfaces, such as modeled in Scenario 1, would be more directly a function of the annual wind direction/wind speed distribution.

The degree to which continued wind erosion has altered and enlarged the initially deposited contamination pattern since the late 1960s is unknown. Based on the modeling performed for Scenario 1, the amount of Pu-239/240 deposited in a year is small compared to the inventory of Pu-239/240 in the soil. This suggests that the overall pattern may be fairly stable, with the outer margins of contamination continuing to expand outward in ever decreasing amounts with time. The extent of continuing redistribution is discussed further in Section 7.3 of this report, which evaluates the

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potential for population dose increases due to continuing contaminant migration over long periods of time (hundreds to thousands of years).

2.5.2 Comparison of Modeling Results to Sampling Data

In FY99, a comparison was made between the modeling results for the chronic, natural resuspension scenario and air quality sampling data from a limited number of ambient samplers at the Site. The comparison used data paired by location and time period. Because the meteorological data were from 1996, the sampling data used in the comparison were also limited to 1996. As described in the FY99 air pathway report (Radian, 1999), the 1996 sampling data set was very limited: samples were routinely analyzed from only three locations in 1996 and the only isotope analyzed for was Pu-239/240 until late in 1996.

The FY99 report determined that the modeling seemed to overestimate concentrations by one to two orders of magnitude. Possible reasons for the apparent overpredictions were explored and several refinements were made to the modeling for FY00 as a result.

A similar comparison has been made for the FY00 chronic, natural resuspension scenario. Impacts at receptors representing 15 RAAMP sampler locations were modeled for this scenario: 14 locations around the perimeter of the Site and 1 location just east of the 903 Pad. These sampler locations are shown in Figure 2-2. RAAMP data for Pu-239/240 and Am-241 were analyzed for 1996 through 1999, so that instead of pairing the data by time and location, as was done in FY99, the data were paired only by location in the current comparison. Although both Site activities and weather have varied from year to year, there is substantial consistency in the overall magnitude and patterns in the sampling data. (Uranium concentrations were not plotted because the relatively large contributions from naturally occurring isotopes, which were not included in the model inputs, would skew the comparison.)

Figures 2-8 through 2-11 show the results of the comparison. Figures 2-8 and 2-9 show the modeled and measured concentrations for Pu-239/240 and Am-241 on a semi-logarithmic scale (the FY99 modeling results are also plotted for comparison). On the left hand side of each graph is a set of data points representing the sampler location just to the east of the 903 Pad (generally downwind from the 903 Pad on an annual average basis and particularly during high wind events, which result in strong, gusty winds from the west). Two samplers were present at that location in 1996, S-107 and S-007. As described in the FY99 air pathway report (see Section 4.3.1 and Appendix C in Radian, 1999), S-007 was an older sampler design that appeared to undersample relative to S-107 under high wind speed conditions. The S-007 sampler was only analyzed for Pu-239/240 and was discontinued in 1997.

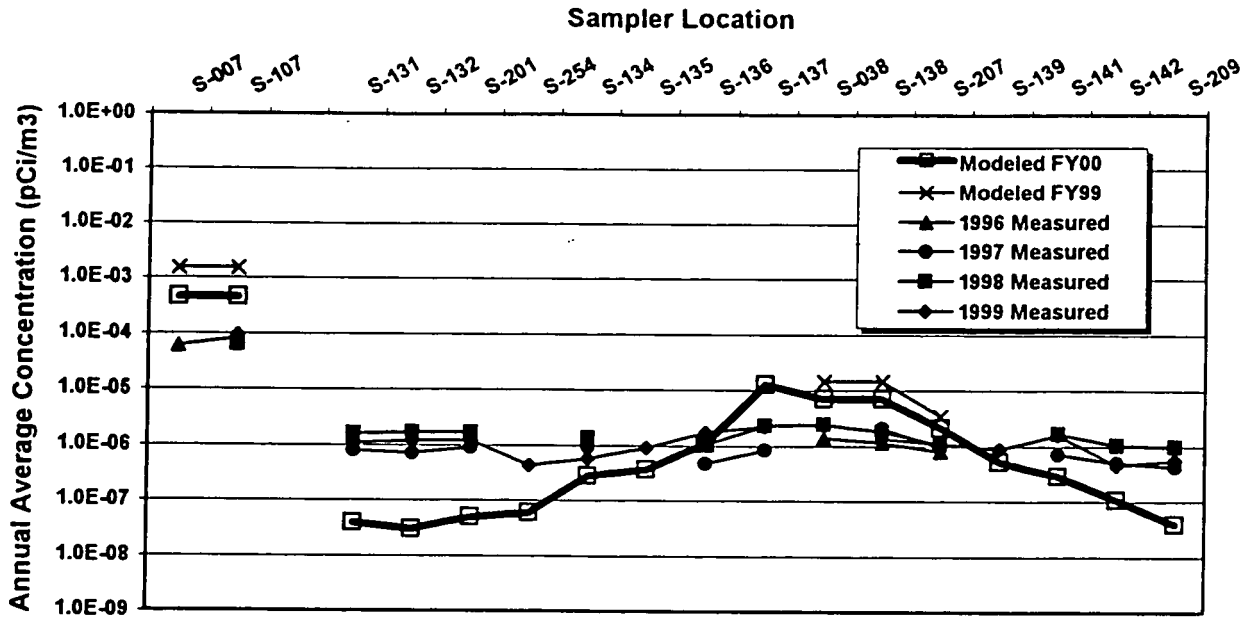

Figure 2-8. Pu-239/240 Measured and Modeled Concentrations

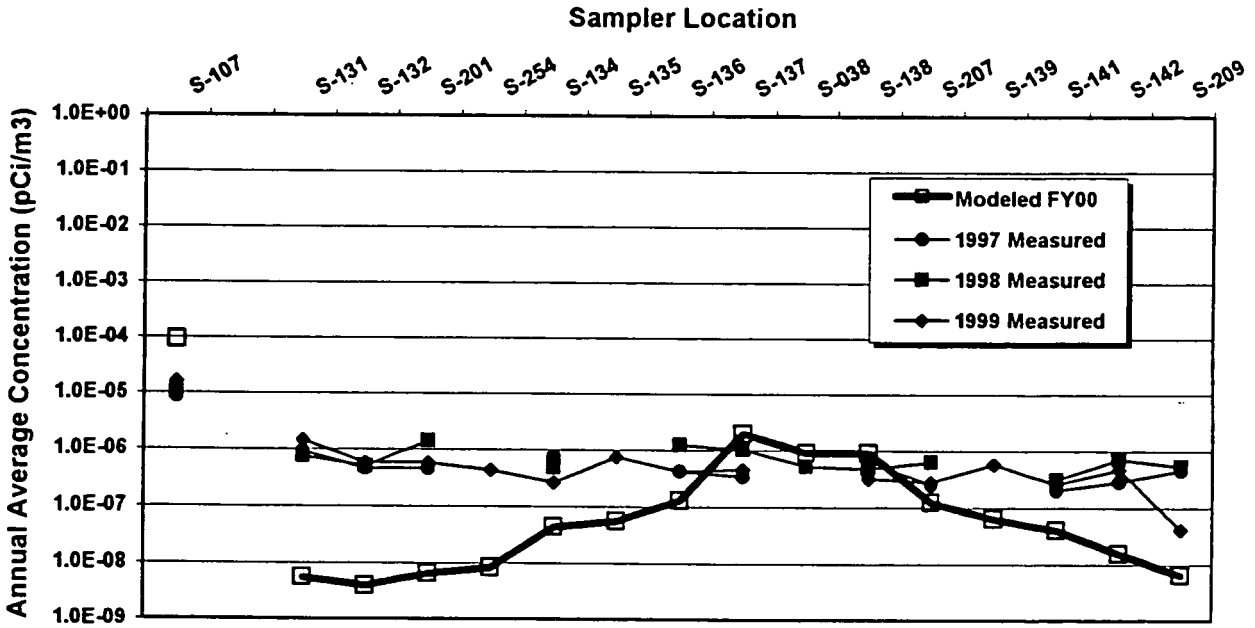

Figure 2-9. Am-241 Measured and Modeled Concentrations

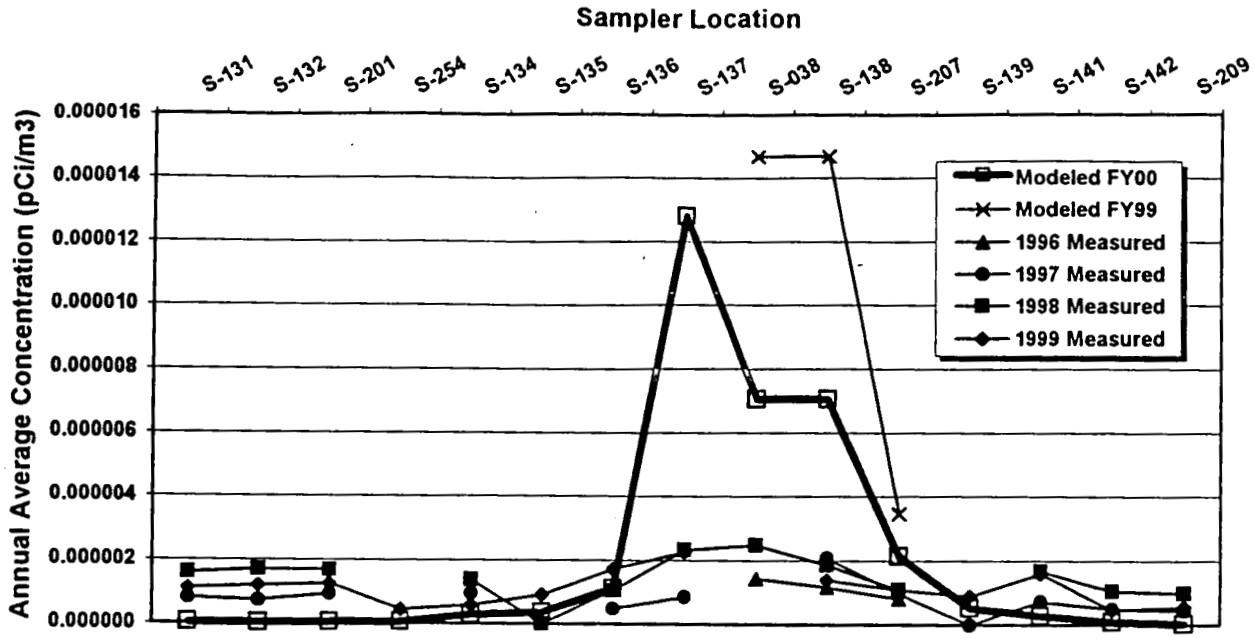

Figure 2-10. Pu-239/240 Measured and Modeled Concentrations at Perimeter Sampler Locations

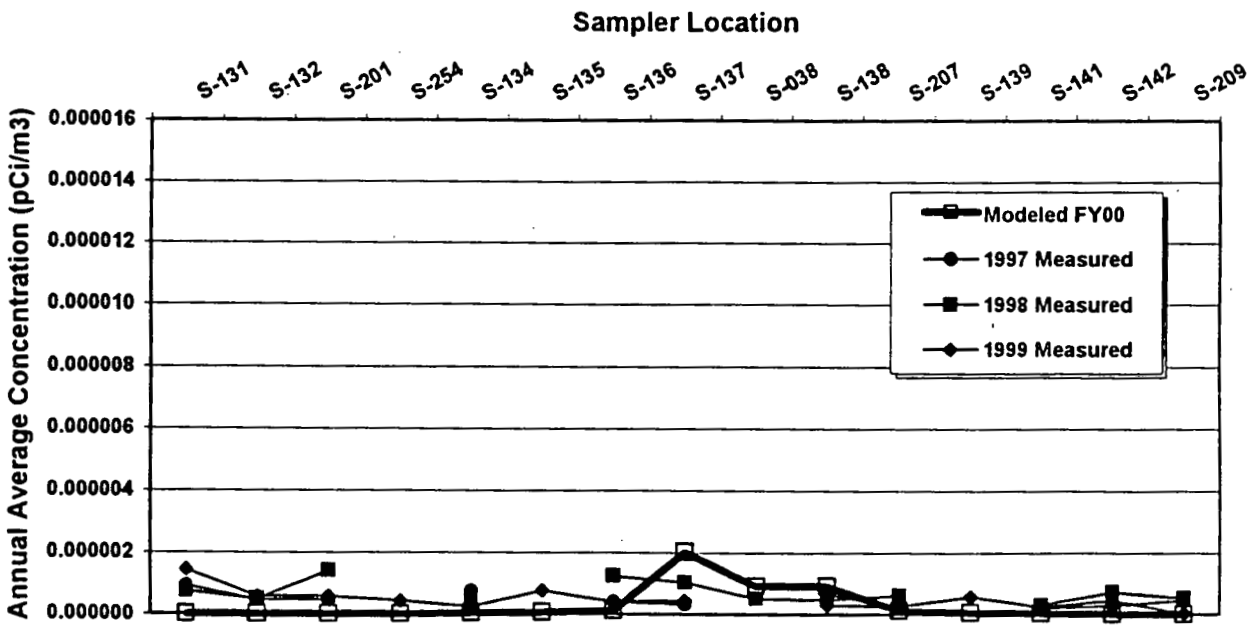

Figure 2-11. Am-241 Measured and Modeled Concentrations at Perimeter Sampler Locations

The remaining data points in Figures 2-8 and 2-9 show perimeter sampler locations beginning at the west gate to the Site (sampler S-131) and continuing clockwise around the Site (see Figure 2-2).

Figures 2-10 and 2-11 show the same data for the perimeter samplers that is plotted in Figures 2-8 and 2-9, but using a nonlogarithmic scale.

An interesting pattern is apparent: modeled results for both actinides are generally higher than measured values (although lower than the FY99 modeled values) in the predominant downwind directions (see, for example, samplers S-007/S-107, S-137, S-038/S-138, and S-207). In contrast, the model appears to underpredict measured concentrations at samplers in other directions from the 903 Pad.

Several measures of the difference between modeled and measured concentrations (error) were made and are shown in Table 2-3. The statistics shown in Table 2-3 reinforce what is apparent from Figures 2-8 through 2-11. The magnitude of the difference between measured and modeled concentrations is greatest for the on-Site samplers S-007 and S-107, and there is more of a discrepancy for Pu-239/240 than for Am-241.

Table 2-3. Comparison of Measured and Modeled Concentrations

Actinide/Locations	Absolute Error			Root Mean Square Error (pCi/m^3)	Median Difference (Measured – Modeled) (pCi/m^3)
	Maximum (pCi/m^3)	Minimum (pCi/m^3)	Mean (pCi/m^3)		
Pu-239/240 All Samplers	3.99×10^{-4}	5.00×10^{-8}	4.23×10^{-5}	1.25×10^{-4}	-1.08×10^{-6}
Pu-239/240 Perimeter Samplers	1.19×10^{-5}	5.00×10^{-8}	2.20×10^{-6}	3.63×10^{-6}	6.50×10^{-8}
Am-241 All Samplers	8.35×10^{-5}	3.49×10^{-8}	6.16×10^{-6}	2.13×10^{-5}	3.25×10^{-7}
Am-241 Perimeter Samplers	1.67×10^{-6}	3.49×10^{-8}	5.85×10^{-7}	4.22×10^{-7}	3.72×10^{-7}

Notes:
Am = americium
pCi/m^3 = picocuries per cubic meter
Pu = plutonium

The ratio of the mean absolute error was compared to the mean observed concentration at a given sampler and expressed as a percentage of the mean observation. These values are graphed in Figure 2-12. The ratios range from a low of approximately 40% to a high value of 670% for Pu-239/240 and a low of 68% and a high of 688% for Am-241. The ratios were highest at the on-Site samplers and at samplers along the eastern fenceline, in the prevailing downwind directions.

What do these comparisons and statistics indicate about the performance of the model? In absolute terms, the errors are small, but they are often comparable to or larger than the observations (measured values) themselves. However, the total error of the measured concentrations at the perimeter samplers is often comparable to or larger than the measured concentrations, as well. In that respect, the modeling replicates measured values at the Site fenceline reasonably well. Put another way, at most sampler locations, the model estimates would fall within a reasonable confidence interval surrounding the measured data.

It is important to understand that the measured concentrations of both Pu-239/240 and Am-241 are extremely small. Laboratories typically qualify reported data using *detection limits*, below which the true value of a measurement cannot be reliably estimated with the given analytical technique. The RAAMP data collected at and around the Site are frequently reported as being below detection limits. Typically, the only concentration data that are consistently above detection limits are Pu-239/240 concentrations at the on-Site sampler location (S-007/S-107) and at the perimeter samplers in the predominant downwind directions (i.e., S-137, S-038/S-138, S-207). Am-241 concentrations at all the samplers shown in Figure 2-2 and Pu-239/240 concentrations at the other samplers are often below detection limits, indicating that the measured concentrations are not necessarily different than zero.

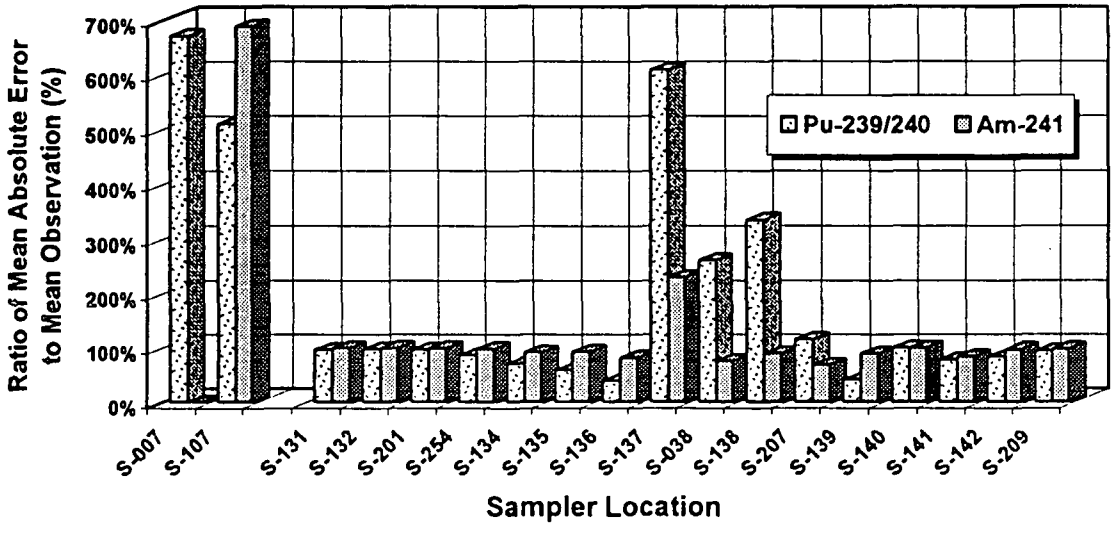

Figure 2-12. Ratios of Error to Observation

The fact that modeled concentrations at samplers in the nondominant wind directions are consistently less than measured values may be at least partially due to the fact that Scenario 1 only accounted for chronic, natural resuspension by wind from contaminated surface soils that were in an undisturbed condition. It is important to realize that there were other sources of actinide emissions at the Site that would have influenced the sampling data (although resuspension from the 903 Pad is an important contributor and, in many years, the major source of Site plutonium and americium emissions). Other sources would include stack emissions from buildings, emissions from projects that disturb contaminated soils or debris, and, possibly, resuspension of contaminated dust by traffic.

With respect to the on-Site samplers and those in the prevailing downwind direction, however, the model predictions are less likely to be within the error bounds of the measured data. While the differences between modeled and measured concentrations are largest at those locations, the confidence intervals surrounding the measured data are actually smaller (tighter) at those samplers.

Although the comparison of model estimates to measured concentration data give a good indication of the overall accuracy of the modeled values, the data do not allow for the separation of error due to the dispersion model formulation and error due to the emission estimation method. In this case, there is no direct way to test the dispersion algorithms for accuracy; however, the ISCST3 model itself has been independently validated by EPA. As discussed in the FY99 air pathway report (Radian, 1999), Gaussian plume models such as ISCST3 are generally accurate to within a factor of two under the best circumstances. The best circumstances would involve a single, elevated point source release in flat terrain. The introduction of groundlevel releases from area sources in complex terrain, such as exist in this application, reduce the expected accuracy of the model. In such cases, the model can be expected to produce "order of magnitude" predictions. The model predictions at S-007/S-107, S-038/S-138, S-137, and S-207 are, for the most part, of the same order of magnitude as the measured concentrations.

Whatever error is inherent in the implementation of the ISCST3 model for this scenario may be considered irreducable; that is, techniques are not available to improve the performance of the dispersion model itself beyond what has been done between FY99 and FY00.

The second factor that may contribute to the model overpredictions in the downwind direction would be inaccuracies in the emission estimation method. Two factors may be considered:

- The equation used to estimate resuspension is based on wind speed raised to the third power. The exponent was estimated from wind tunnel data taken in OU3 to the east of the Site. As discussed in the FY99 air pathway report (Radian, 1999),

the emission equation was based on a very small number of data points. While the exponent is comparable to that estimated for resuspension at other sites and in other studies (see Radian, 1999 Section 2.3.4), it may be either high or low relative to the "true" exponent. If the exponent is too large, emissions during high wind events (which generally blow emissions nearly due east from the 903 Pad area) would be overestimated. That could result in the pattern of overprediction apparent in Figures 2-8 through 2-11.

- A second potential factor that was discussed in some detail in the FY99 air pathway report is possible "dilution" of the particulate matter available for resuspension relative to the activity of the underlying soil. Dust within the vegetation canopy may consist partly of the ambient, underlying soil and partly of dust advected into the contaminated areas and then deposited. For example, a measurement by Langer (1986) that is discussed further in Appendix A to this report showed that dust removed from plant surfaces in the 903 Pad area contained only 20% the activity of the underlying soil.

  The contaminated soils around the 903 Pad are the primary sources of resuspendable actinides in the area. In contrast, area-wide sources of suspended particulate matter, uncontaminated with actinides, are numerous. Over time, at any given point, only a portion of the total atmospheric loading of particulate matter will originate from Site sources. That fraction of suspended particulates that are in turn deposited to the ground, water, or vegetation surfaces will therefore have actinide concentrations that represent a weighted average of the clean and contaminated contributions.

  The modeling used a simplified assumption in FY99 and again in FY00 that the dust that was resuspended from contaminated areas of the Site contained actinides in the same concentration as the underlying soil (i.e., that there was no dilution). Although it is likely that dilution occurs, the data available at this time are insufficient to quantify it. If, in fact, the resuspended dust is actually diluted relative to the underlying soil actinide concentrations, model overprediction would be expected and the effect would be greatest downwind of the most highly contaminated areas (which would be the areas most affected by dilution).

2.6 Conclusions

The results of Scenario 1 show maximum concentrations and deposition of actinides due to chronic wind erosion to the east or southeast of the primary source areas on Site. The specific locations vary by actinide and reflect the differing distributions of various isotopes in Site soils, coupled with the prevailing direction of higher speed winds in the 1996 meteorological data set.

A comparison of modeled estimates to measured actinide concentrations showed that the Scenario 1 modeling underestimated measured actinide concentrations at samplers in the nondominant wind directions, while overestimating concentrations to the east and southeast of the source areas. The model performance at the locations where concentrations appeared to be underpredicted was generally within the accuracy of the measurements themselves. Model overpredictions in the direction of the stronger winds at the Site are probably at least partly due to inaccuracies in the emission estimation method. Even so, the model overpredictions were reduced from the FY99 modeling and are now within an order of magnitude of the measured concentrations.

The accuracy of the emission estimation method could be improved with additional data regarding the dependency of Site soil resuspension on wind speed and the degree to which dust available for resuspension is diluted relative to underlying soil concentrations of actinides. Additional wind tunnel data being collected in FY00 will help refine the emission estimation equation. If air pathway estimates prove to be of concern, additional data collection regarding dilution may also be warranted. In the interim, it appears that maximum concentrations of actinides due to chronic, natural resuspension will generally be overpredicted, thereby making the model results conservative.

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3.0 SCENARIO 2: 903 PAD REMEDIATION

Remediation activities, designed to reduce soil contamination at the Site to below negotiated action-level criteria, will result in short-term emissions of actinides as contaminated soil is disturbed through excavation, handling, and disposal. While such cleanup activities will reduce future actinide migration potential by eliminating or reducing the initial source, enhanced emissions during remediation may result in short-term increases in exposure through the air pathway, as well as redeposition of actinide-containing particles downwind.

Because the 903 Pad area has the highest surface soil levels of plutonium and americium at the Site, as well as uranium contamination, cleanup of this area was chosen to represent a remediation scenario for modeling. Both an annual scenario, representing activities during the period with maximum potential for actinide emissions, and a short-term, high wind event, were modeled. The two scenarios, the model input data, and the results of the modeling are described below. Technical details of the calculations and results of the modeling are provided in Appendices C1 and C2.

3.1 903 Pad Remediation Annual Scenario

This section discusses the annual remediation scenario that was simulated. In addition, a short-term, high wind event was also examined. The short-term event is described in Section 3.2.

3.1.1 Scenario Description

Soils in the 903 Pad area were contaminated in the 1960s with actinides released from stored drums of waste cutting oil. The cutting oil contained weapons-grade plutonium particles, which leaked into the underlying soil. Americium contamination is also associated with the 903 Pad area due to ingrowth of americium into decaying weapons-grade plutonium (Am-241 is formed by radioactive decay of Pu-241 atoms). Though the leaking drums were later removed and the area covered with gravel and asphalt in an attempt to immobilize the spill, winds moved a significant amount of contaminated dust a short distance east and southeast of the 903 Pad before and during the mitigation effort (this area is known as the Pad Field). Plutonium particles attached to soil particles remain available for resuspension through natural erosive forces. The 903 Pad and Pad Field constitute the largest and most significant source area at the Site for airborne actinide emissions from remediation activities.

Several remediation alternatives for the 903 Pad and adjacent areas have been proposed and reviewed for possible implementation. The most likely scenario, involving excavation and off-Site disposal of contaminated soil followed by backfilling of

excavated cells with clean soil from off Site, was selected for modeling while the review of alternatives continues.

Remediation projects at the Site are performed in accordance with the Rocky Flats Cleanup Agreement (RFCA). RFCA is a negotiated, interagency agreement governing CERCLA and Resource Conservation and Recovery Act (RCRA) cleanup activities at the Site. RFCA defines Tier I and Tier II action levels based on concentrations of various contaminants in the water or soil, where contamination above the higher Tier I action levels suggests cleanup may be necessary, while contamination above Tier II represents contaminant concentrations that require further evaluation. The applicable soil action levels for the remediation scenario are (DOE et al., 1996):

- Tier I Surface Soil Action Levels (Open Space Use):
  —Am-241 215 pCi/g
  —Pu-239/240 1,429 pCi/g
  —U-233/234 1,738 pCi/g
  —U-235 135 pCi/g
  —U-238 586 pCi/g

- Tier II Surface Soil Action Levels (Open Space Use);
  —Am-241 38 pCi/g
  —Pu-239/240 252 pCi/g
  —U-233/234 307 pCi/g
  —U-235 24 pCi/g
  —U-238 103 pCi/g

The scenario modeled for the 903 Pad and Pad Field assumed the following remediation objectives:

- All soils contaminated above Tier I levels will be excavated and disposed of off Site; and

- All soils contaminated above Tier II levels that are co-located above or below a Tier I contamination area will be excavated and disposed of off Site.

To meet these objectives and to address regulatory requirements, the following assumptions were made regarding the project:

- All backfill will be uncontaminated material obtained from off Site;

- Active remediation involving contaminated soil excavation and handling will be 12 months in duration;

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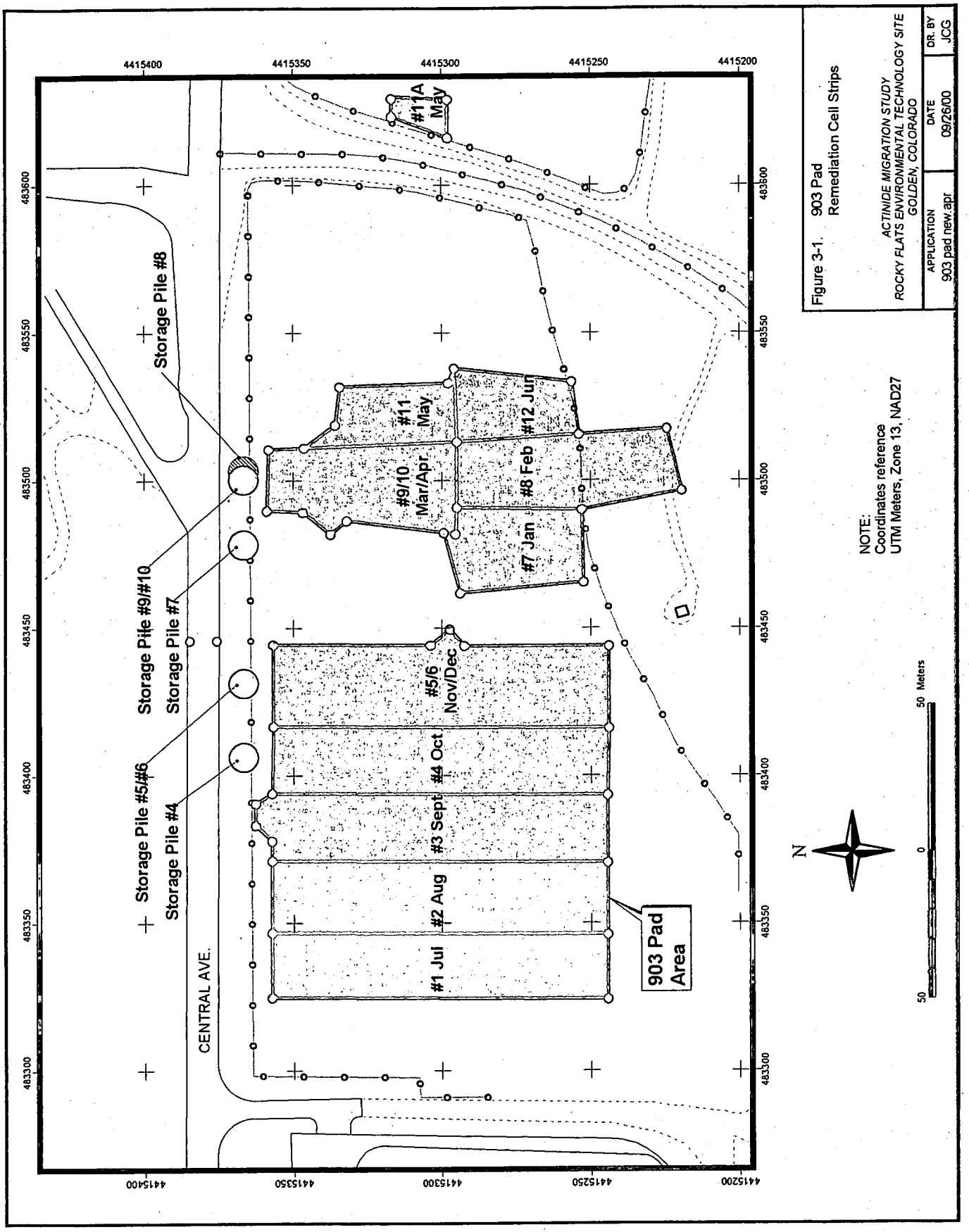
- Excavated material will be stockpiled into conical storage piles, analyzed, then containerized according to contamination level;
- Exposed soil surface will be minimized to control dust and actinide emissions by limiting the area excavated each month;
- Stockpiles and exposed soils will be treated with water spray to control dust; and
- Work will cease during high wind events to minimize potential dust transport.

Modeling involved the following additional assumptions about the design of the remediation plan, which were developed in cooperation with the 903 Pad remediation project staff:

- The 903 Pad and Pad Field will be subdivided into discrete work areas, called cell strips (see Figure 3-1).
- Each cell strip will be excavated and then backfilled in series, with no more than one cell strip undergoing excavation at any given time.
- Each cell strip will take one month to excavate and backfill, with two exceptions. The two exceptions will each take two months to complete (though the surface areas of each cell strip are roughly equivalent, they vary significantly in contaminated soil volume).
- Cell strips will be excavated from west to east to minimize cross-contamination by prevailing westerly winds.
- Remediation work schedule will consist of 8-hour days and 40-hour weeks.
- Remediation will begin in July of the year scheduled.
- Excavation will be performed by backhoe and/or trackhoe.
- Stockpiled soil will be containerized using front-end loaders following analysis and categorization.
- Truck traffic removing containerized soil will be assumed to cross soils contaminated at Tier II levels (*de facto* unpaved roadways).
- Truck traffic bringing in clean fill will not cross contaminated soil.


4415400
4415350
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483600
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483300
#11A May
#11 May
#12 Jun
#8 Feb
#9/10 Mar/Apr
#7 Jan
#5/6 Nov/Dec
#4 Oct
#3 Sept
#2 Aug
#1 Jul
Storage Pile #8
Storage Pile #9/#10
Storage Pile #7
Storage Pile #5/#6
Storage Pile #4
CENTRAL AVE.
903 Pad Area
NOTE:
Coordinates reference
UTM Meters, Zone 13, NAD27
N
50 Meters
0
50
Figure 3-1. 903 Pad
Remediation Cell Strips
ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO
APPLICATION
903 pad new.apr
DATE
09/26/00
DR. BY
JCG

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- All trucks will cause fugitive dust emissions from uncontaminated paved roadways and will enter and exit the Site from the west (Highway 93).

- Contouring of backfilled cell strips will be performed by bulldozer.

The modeling scenario did not account for use of a tent or weather enclosure, though such a structure is under consideration. Potential emissions have been maximized for the model by assuming that no enclosure would be used.

3.1.2 Emission Estimation

Emission rates for particulate matter and actinides from the 903 Pad remediation project have been estimated based on the objectives and supporting assumptions presented in Section 3.1.1. Fugitive dust emissions from sources such as outdoor storage piles, traffic on paved and unpaved roads, and excavation of soil have been the subject of extensive research by the EPA and others. Emission factors, which are estimates of the rate at which pollutants are released to the atmosphere as a result of some activity, divided by the unit measure of that activity, have been developed by these organizations. An example of an emission factor relates a given number of grams of dust emitted per mile of vehicle travel on an unpaved road.

Particulate Emission Estimates

As presented in Appendix C1 of this report, particulate emissions due to remediation activities have been estimated using EPA's *Compilation of Air Pollutant Emission Factors, Fifth Edition* (AP-42) (EPA, 1995b). Sources of particulate emissions from the remediation scenario included backhoe excavation, material handling by front-end loader, bulldozer activity, truck traffic on paved and unpaved roads, and storage pile and exposed ground emissions due to wind.

Emissions were calculated for total particulate matter (PM, generally ≤ 30 μm aerodynamic equivalent diameter) and particulate matter ≤ 10 μm aerodynamic equivalent diameter (PM_{10}). Actinide resuspension was estimated based on particulate emissions.

Actinide Emission Estimates

Actinide resuspension rates are a function of particulate emission rates. The distribution of actinides within 903 Pad area soils has been determined in units of picocuries of radioactivity per gram of soil (pCi/g). The estimated activity from each isotope associated with soils in each cell strip was input to the model based on the PM emissions from each cell strip. Soil surveys have been used to determine the total activity of soil-bound isotopes in each cell strip. Since multiple soil survey data points were available for each cell strip, at a variety of depths, soil isotopic concentrations were averaged. This

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provided a single concentration value for each isotope that could be associated with every gram of soil excavated from a given cell strip (see Table C1-8 in Appendix C1).

Paved-road traffic was assumed to have no actinide release potential. Remediation activities including excavation, excavated soil handling, excavated soil storage pile loading and unloading, and wind erosion of excavated soil piles and exposed excavation surfaces were assumed to resuspend actinide-laden dust.

To estimate the actinide migration potential of carryout onto roads from remediation project traffic, it was assumed that unpaved roadways within the 903 Pad and Pad Field areas will become contaminated to Tier II levels during excavation. Therefore, unpaved roadway particulate emissions associated with excavation would include actinides. To avoid overestimating this potential, particulate emissions from trucks bringing in clean fill were assumed not to include actinide contamination.

Roads in the immediate area of the 903 Pad were surfaced with soil and road base brought in from off Site during the 1980s. In past studies, the unpaved roads on Site were not considered source areas for airborne actinides because the roadway material was assumed to be uncontaminated. As discussed previously, this assumption will be tested during FY01.

Actinide releases were estimated for remediation activities over a 1-year period. Downwind impacts of these actinide releases received additional refinement within the model, based on soil particulate sizing and actinide partitioning as a function of soil particle size, as described below.

3.1.3 Modeling Methods

The most likely scenario for remediation of the 903 Pad would involve soil disturbance and soil handling over a 12-month period. Therefore, to estimate air transport of contaminants from remediation activities, the event was modeled over the course of one complete calendar year, with source strengths and locations that varied according to the progression and the nature of the remediation activity. The ISCST3 model was used to predict 24-hour and annual concentrations of PM_{10} and annual concentrations and dry deposition of actinides. Meteorological input consisted of the 1996 on-Site data that has been used for previous (FY99) modeling of airborne actinide migration (see Radian, 1999). Model receptors were those described in Section 2.3.2 of this report.

Emission Sources and Locations

To model the 903 Pad remediation, the pad was first divided into emission source areas (cell strips; see Figure 3-1). Each cell strip represents an area over which remediation activity would occur during a specific time during the 12-month event. For most of the

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cell strips, remediation activity would occur during a one-month period. For some cell strips, remediation would require two months to complete rather than one month, and therefore activity was simulated to persist over the course of two consecutive months for these sources. Certain cell strip pairs, such as 11 and 11a (see Figure 3-1), would likely be remediated simultaneously over the course of a single month and were modeled as being active at the same time during that month.

Each emission source associated with the 903 Pad remediation was characterized as a ground-based area source. Emissions associated with unpaved roads, soil handling, and wind erosion were applied throughout the area of a given cell strip. Paved road emissions were applied to a segment of road that led from the north edge of the 903 Pad toward Highway 93 to the west of the Site.

Although the modeled scenario accounts for a storage pile to be constructed during the remediation of each cell strip, particulate emissions were not associated with each pile. This was because threshold wind speeds, above which wind erosion emissions occur, were not achieved in each month of the simulated remediation event. On-Site meteorological data for 1996, which was used for input to the ISCST3 model, was also used to determine if wind speeds in a given month would be high enough to generate wind erosion from the individual piles, based on AP-42 storage pile emission algorithms (EPA, 1995b).

Emissions from each storage pile were applied over a circular area with a diameter of 10 m. The storage piles were assumed to be present only during the active remediation of a given strip. In other words, once the remediation of a cell strip was completed during a given month, the storage pile for that strip was considered removed (and the next strip's storage pile was activated). Each storage pile was located approximately midway between the north edge of the applicable cell strip and the paved road to the north of the cell strips.

Several of the emission sources, including unpaved roads, paved roads, and soil handling, were assumed to be active during only limited hours of the day. Hourly emission files that accounted for this variation were input to the ISCST3 model. For the other source types, such as cell strip wind erosion and storage pile wind erosion, a constant emission rate was applied during the month that a particular cell strip was active. Table 3-1 summarizes the various types of sources that were modeled for the 903 Pad.

Emission Rates

To estimate the emission rates for various contaminants associated with the remediation, PM_{10} and PM emissions were first estimated for each source type and cell strip, as described in Section 3.1.2. To arrive at actinide emissions for sources within a given

Table 3-1. Sources of Particulate and Actinide Emissions—903 Pad Remediation

Action	Description	Particulate Emissions	Actinide Emissions
Excavation of Cell Strips			
Unpaved Roads	Travel near cell strip from 0800-1600 local time during Monday through Friday workweek	PM_{10} emissions in $g/m^2/s$, controlled 50% by water sprays, applied over entire cell strip area	PM emissions in $g/m^2/s$, controlled 50% by water sprays, multiplied by Tier II soil concentrations in pCi/g
Paved Roads	Travel to and from cell strip to Highway 93 from 0800-1600 local time during Monday through Friday workweek	PM_{10} emissions in $g/m^2/s$, applied over area of road segment	—
Soil Handling	Soil handling with backhoe, front-end loader, or dump truck and storage pile loading from 0800-1600 local time during Monday through Friday workweek	PM_{10} emissions in $g/m^2/s$, applied over entire cell strip area	PM emissions in $g/m^2/s$, multiplied by cell strip borehole concentration in pCi/g
Clean Fill Activities			
Unpaved Roads	Travel near cell strip from 1000-1400 local time during Monday through Friday workweek	PM_{10} emissions in $g/m^2/s$, controlled 50% by water sprays, applied over entire cell strip area	—
Paved Roads	Travel to and from cell strip to Highway 93 from 1000-1400 local time during Monday through Friday workweek	PM_{10} emissions in $g/m^2/s$, applied over area of road segment	—
Soil Handling	Soil handling with front-end loader, dump truck, or bulldozer from 1000-1400 local time during Monday through Friday workweek	PM_{10} emissions in $g/m^2/s$, applied over entire cell strip area	—
Miscellaneous Sources			
Wind Erosion	Wind erosion over entire cell strip (during active remediation on that strip)	PM_{10} emissions in $g/m^2/s$, applied over entire cell strip area	PM emissions in $g/m^2/s$, multiplied by cell strip borehole concentration in pCi/g
Storage Pile	Erosion from storage pile associated with cell strip (if applicable)	PM_{10} emissions in $g/m^2/s$, controlled 50% by water sprays, applied over circular area north of appropriate cell strip	PM emissions in $g/m^2/s$, multiplied by cell strip borehole concentration in pCi/g

Notes:

$g/m^2/s$ = grams per square meter per second
— = not applicable
pCi/g = picocuries per gram
PM_{10} = particulate matter less than 10 micrometers
PM = particulate matter

strip, the PM emission rates were multiplied by soil activity levels (in units of pCi/g) for actinides.

As an example of the method used to determine the emission rate for a particular actinide, the calculation of Pu-239/240 emissions from unpaved roads within Cell Strip 1 is presented here. Based on the methodology described in Section 3.1.2, the PM emissions for unpaved roads in Cell Strip 1 were estimated to be 1.58×10^{-4} g/m^2/s. The Tier II soil concentration for Pu-239/240 of 252 pCi/g of soil was then multiplied by the PM emission rate to arrive at the model input for Pu-239/240 emissions. A control factor of 0.5 was also included to account for 50% emission control from the effect of water sprays on the unpaved surfaces. The emission rate used to model Pu-239/240 impacts from unpaved roads within Cell Strip 1 was therefore:

$$(1.58 \times 10^{-4}\ g/m^2/s) \times (0.5) \times (252\ pCi/g) = 1.99 \times 10^{-2}\ pCi/m^2/s$$

Appendix C1 provides a complete summary of the soil concentration levels for the 903 Pad cell strips.

Model Options

The ISCST3 model was employed with the TOXICS option for dry deposition calculations, plume depletion by dry deposition, and rural dispersion coefficients (as described for Scenario 1, Section 2.3.2).

The ISCST3 deposition algorithm requires the input of source variables for settling and removal. The particle data used in the 903 Pad remediation modeling are the same as those used in modeling Scenario 1. The data are shown in Table 2-1 and discussed in Section 2.3.2 of this report.

To properly account for plume depletion when modeling concentration and deposition of actinide activity, the activity fractions shown in Table 2-1 were input for the mass fractions for the three particle size categories. To model the impacts of PM_{10} emissions alone, a single particle size with a mean particle diameter of 6.51 μm (lower bound of 1μm and upper bound of 10 μm) was used within the model. Additionally, a mass fraction of 1.0 was assigned for the PM_{10} emissions, as was a particle density of 2.65 g/cm^3.

3.1.4 Model Results

This section describes the modeling results for the 903 Pad annual remediation scenario. Table 3-2 summarizes the maximum PM_{10} and actinide concentrations predicted to result from the 903 Pad annual remediation scenario. The results are discussed below.

Table 3-2. Results Summary—903 Pad Annual Remediation Scenario

Pollutant	Averaging Period	Maximum Concentration	
		On Site	Off Site
PM_{10}	24-hour	112.0 $\mu g/m^3$	3.8 $\mu g/m^3$
	Annual	4.3 $\mu g/m^3$	0.4 $\mu g/m^3$
Pu-239/240	Annual	2.8×10^{-3} pCi/m^3	4.6×10^{-6} pCi/m^3
Am-241	Annual	5.6×10^{-4} pCi/m^3	9.1×10^{-7} pCi/m^3
U-233/234	Annual	3.6×10^{-5} pCi/m^3	5.7×10^{-8} pCi/m^3
U-235	Annual	4.7×10^{-6} pCi/m^3	7.8×10^{-9} pCi/m^3
U-238	Annual	1.3×10^{-4} pCi/m^3	1.9×10^{-7} pCi/m^3

Notes:
Am = americium
pCi/m^3 = picocuries per cubic meter
PM_{10} = particulate matter less than 10 micrometers
Pu = plutonium
U = uranium
$\mu g/m^3$ = micrograms per cubic meter

Fine Particulate Matter (PM_{10}) Concentration

The highest estimated 24-hour concentration of PM_{10} due to the 903 Pad remediation was 112.0 micrograms per cubic meter ($\mu g/m^3$). This impact was estimated for the receptor representing the S-107 sampler, located just to the east of the pad, and was predicted to occur while the cell strips nearest the S-107 sampler were active. The maximum 24-hour impact at or beyond the Site fenceline was estimated to be 3.8 $\mu g/m^3$.

Figure C2-1 in Appendix C2 shows an isopleth plot for the maximum estimated 24-hour PM_{10} impacts. As shown in Figure C2-1, estimated PM_{10} impacts along a line west of the pad toward the facility boundary would be relatively high. This is due to the emission source that represented travel of haul trucks over the paved road surfaces leading to Highway 93.

The maximum PM_{10} concentration over the annual period during which 903 Pad remediation would occur was estimated to be 4.3 $\mu g/m^3$. This annual impact was predicted to occur near the northwest corner of the pad at the receptor representing the S-119 sampler. The maximum annual off-Site impact was estimated to be 0.4 $\mu g/m^3$. Figure C2-2 shows the estimated annual PM_{10} impacts for the 903 Pad remediation. As with the 24-hour impacts, the higher estimated annual impacts along a line west of the pad toward Highway 93 were due to paved road emissions.

EPA has established National Ambient Air Quality Standards (NAAQS) for PM_{10}. The NAAQS define a level of air quality that is protective of public health, with an adequate

margin of safety. The 24-hour NAAQS for PM_{10} is 150 $\mu g/m^3$; the annual standard is 50 $\mu g/m^3$. The standards do not apply within the fenceline but, instead, regulate air quality to which the general public is exposed.

To determine whether the 903 Pad remediation scenario as modeled would impact the standards, it is necessary to add the project impact to "background" air quality values; that is, the concentration of PM_{10} in the air due to all other sources. The Colorado Department of Public Health and Environment (CDPHE) monitors PM_{10} levels at five locations around the Site boundary. Based on monitoring data taken between 1994 and 1999, the highest recorded background levels of PM_{10} in the vicinity of the Site were 87 $\mu g/m^3$ 24-hour average and 16.6 $\mu g/m^3$ annual average. The maximum off-Site impacts of the 903 Pad remediation scenario, plus background concentrations, would be approximately 90.8 $\mu g/m^3$ 24-hour average and 17.0 $\mu g/m^3$ annual average, well within the NAAQS limits.

Pu-239/240 Concentration and Deposition

The annual concentration of Pu-239/240 due to the 903 Pad remediation was predicted to be highest at a receptor located near the northeast corner of the main 903 Pad. The magnitude of this maximum annual estimated impact was 2.8×10^{-3} pCi/m^3. Estimated impacts were below 1.0×10^{-4} pCi/m^3 within 500 m of the location of the maximum impact. The maximum off-Site impact was predicted to be approximately 4.6×10^{-6} pCi/m^3 at the south fenceline. Figure C2-3 shows the distribution of annual concentration estimates for Pu-239/240.

Figure C2-4 shows the distribution of estimated annual dry deposition of Pu-239/240 in $pCi/m^2/yr$. As expected, the annual maximum was predicted to be centered near the 903 Pad.

Am-241 Concentration and Deposition

As with Pu-239/240, the annual concentration of Am-241 was estimated to be highest at a receptor located near the northeast corner of the main 903 Pad. The maximum estimated annual impact was 5.6×10^{-4} pCi/m^3. Estimated impacts were below 5.0×10^{-5} pCi/m^3 within 500 m of the location of the maximum predicted impact and the maximum off-Site impact was predicted to be approximately 9.1×10^{-7} pCi/m^3 at the south fenceline. Figure C2-5 shows the distribution of annual concentration estimates for Am-241.

Figure C2-6 shows the distribution of estimated annual dry deposition of Am-241 in $pCi/m^2/yr$. The distribution of deposition follows a similar pattern to the pattern displayed by Pu-239/240, but with a lower magnitude.

Uranium U-233/234 Concentration and Deposition

The maximum annual concentration of U-233/234 was estimated to be 3.6×10^{-5} pCi/m^3 at the same receptor that yielded the maximum estimates for Pu-239/240 and Am-241. Estimated impacts were below 1.0×10^{-6} pCi/m^3 within approximately 500 m of the location of the maximum predicted impact and the maximum off-Site impact was predicted to be approximately 5.7×10^{-8} pCi/m^3 at the south fenceline. Figure C2-7 shows the distribution of annual concentration estimates for U-233/234.

Figure C2-8 shows the distribution of estimated annual dry deposition of U-233/234 in pCi/m^2/yr. The distribution of deposition follows a similar pattern to the pattern displayed by Pu-239/240 and Am-241, but with a much lower magnitude.

Uranium U-235 Concentration and Deposition

The maximum annual concentration of U-235 was estimated to be 4.7×10^{-6} pCi/m^3 at the same receptor yielding the maximum estimates for other actinides described above. Estimated impacts were below 1.0×10^{-7} pCi/m^3 within approximately 600 m of the location of the maximum predicted impact and the maximum off-Site impact was predicted to be approximately 7.8×10^{-9} pCi/m^3 at the south fenceline. Figure C2-9 shows the distribution of annual concentration estimates for U-235.

Figure C2-10 shows the distribution of estimated annual dry deposition of U-235 in pCi/m^2/yr. The distribution of deposition follows a similar pattern to U-233/234, but with a lower magnitude.

Uranium U-238 Concentration and Deposition

The maximum annual concentration of U-238 was estimated to be 1.3×10^{-4} pCi/m^3 at the same receptor yielding the maximum estimates for the other actinides. Estimated impacts were below 1.0×10^{-5} pCi/m^3 within 400 m of the location of the maximum predicted impact and the maximum off-Site impact was predicted to be approximately 1.9×10^{-7} pCi/m^3 at the south fenceline. Figure C2-11 shows the distribution of annual concentration estimates for U-238.

Figure C2-12 shows the distribution of estimated annual dry deposition of U-238 in pCi/m^2/yr. The distribution of deposition follows a similar pattern to the pattern displayed by other actinides.

Maximum Effective Dose Equivalent for 903 Pad Remediation

The results of the concentration modeling were converted to effective dose equivalent in units of mrem using the conversion approach that was described in Section 2.4. Table 3-3 lists the estimated on-Site and off-Site maximum EDE for each actinide and the conversion factor that was applied to convert from pCi/m^3 to mrem.

Table 3-3. Maximum Estimated Annual Actinide Concentration and EDE for 903 Pad Remediation Scenario

Isotope	Maximum Estimated Annual Concentration (pCi/m^3)		Factor for Conversion of pCi/m^3 to mrem	Maximum Estimated Annual EDE (mrem)	
	On Site	Off Site		On Site	Off-Site
Pu-239/240	2.8×10^{-3}	4.6×10^{-6}	5,000	14.1	0.02
Am-241	5.6×10^{-4}	9.1×10^{-7}	5,263	3.0	0.005
U-233/234	3.6×10^{-5}	5.7×10^{-8}	1,299	0.05	7.4×10^{-5}
U-235	4.7×10^{-6}	7.8×10^{-9}	1,408	0.01	1.1×10^{-5}
U-238	1.3×10^{-4}	1.9×10^{-7}	1,205	0.2	2.3×10^{-4}

Notes:
Am = americium
mrem = millirem
pCi/m^3 = picocuries per cubic meter
Pu = plutonium
U = uranium

3.2 High Wind (Short-Term) Scenario Description

This section discusses the second 903 Pad remediation scenario that was examined. The scenario simulated an assumed high wind event during a period when remediation would expose contaminated soils to wind erosion.

3.2.1 Scenario Description

As described previously, the 903 Pad and Pad Field comprise the largest single area source of resuspendable actinides at the Site. The remediation strategy described for the 903 Pad has the potential to release currently sequestered actinide particles. High wind events, marked by sustained winds above 30 miles per hour (mph) and gusts above 100 mph, are not uncommon at the Site. Therefore, investigating how sustained high winds would impact 903 Pad remediation emissions and consequent actinide dispersion and deposition was warranted.

In accordance with Site operating procedures, outdoor work is not performed when sustained winds equal or exceed 45 mph, and outdoor work may only proceed with the concurrence of a health and safety professional when winds are between 35 mph and 45 mph. Based on these policies, the high wind event modeled for the 903 Pad was assumed to occur during a period when active remediation had ceased. Particulate and actinide emissions, then, would result only from wind erosion of storage piles and exposed ground.

The high wind event modeled during 903 Pad remediation was based on 19 April 1996 meteorological data (see Appendix C1). This day had the greatest sustained wind speeds for any day in the 1996 through 1999 timeframe for which complete meteorological records are available (it should be noted that high wind events sometimes damage meteorological instruments).

3.2.2 Emission Estimation

This section describes the assumptions made in calculating emissions for a high wind event.

Particulate Emission Estimates

Using the algorithms described in Appendix C1, particulate emissions from exposed soil and a stockpile were estimated based on the following assumptions:

- The exposed area would include all of Cell Strip 1, which has the highest soil concentrations of plutonium and americium in the 903 Pad area;
- The storage pile containing excavated Cell Strip 1 soil would be unprotected from the wind other than by water spray, which would prove ineffective within a very short time (i.e., no credit for control was factored into the particulate emission estimates);
- One disturbance per hour would occur to exposed soil and pile surfaces throughout the day (due to saltation, for example); and
- The high wind event would be 24 hours in duration.

Actinide Emission Estimates

As described previously, the resuspension of actinides is dependent on soil particle properties, and not the properties of the individual radioactive particles. The concentration of each isotope within Cell Strip 1 was calculated as the average of all concentration data for each isotope within the cell (see Table C1-2 in Appendix C1). The

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average concentration for each isotope, in pCi/g, was multiplied by the particulate emission rate in g/m^2/s to estimate isotopic emission rates in pCi/m^2/s.

3.2.3 Modeling Methods

As described in Section 3.2.1, meteorological data measured at the Site during a 24-hour period in 1996 were used as model input to estimate the impacts a high wind event during 903 Pad remediation. The chosen 24-hour period had an average wind speed of 34 mph (measured at 10 m height), and exhibited wind speed and wind direction characteristics typical of high wind events at the Site. To assess the potential influence of such a high wind event occurring during 903 Pad remediation, the ISCST3 model was used to predict 24-hour PM_{10} concentrations, and 24-hour concentrations and dry deposition of actinides.

Model Options

Meteorological conditions for the 24-hour high wind event included sustained winds that averaged 34 mph. Hourly average wind speeds ranged from 23.9 mph to 49.9 mph during the day, with one 8-hour period for which hourly average wind speeds all remained above 40 mph. Hourly average wind directions during the period were very persistent, with the overall average wind direction blowing toward the east-southeast direction.

Model receptors and the model technical options that were used for the high wind event simulation were the same as those used for the 903 Pad remediation annual modeling described in Section 3.1.3. Each of the emission sources was modeled as a ground-based area source. Emissions associated with wind erosion from exposed surfaces were applied throughout the area of Cell Strip 1. Storage pile emissions were estimated for two configurations of erosion potential. The two configurations reflect the different erosion potentials of storage pile surfaces as a function of impact angle to the wind. Both sets of storage pile emissions were applied separately over a circular area source centered just to the north of the cell strip. The diameter of the area sources varied with the size of the erodible area of the pile, and the size of the erodible area was a function of the total pile size and wind speeds.

The ISCST3 model was employed with the TOXICS option for dry deposition calculations (as described in Section 3.1.3), plume depletion by dry deposition, and rural dispersion coefficients. Source variables for settling and removal were the same as those used for modeling the 903 Pad annual scenario.

3.2.4 Model Results

This section describes the modeling results for the high wind scenario. The results are summarized in Table 3-4.

Table 3-4. Results Summary—903 Pad Remediation High Wind Event Scenarios

Pollutant	Averaging Period	Maximum Concentration	
		On Site	Off Site
PM_{10}	24-hour	0.004 μg/m³	6.0×10^{-5} μg/m³
Pu-239/240	24-hour	4.6×10^{-4} pCi/m³	2.2×10^{-5} pCi/m³
Am-241	24-hour	9.6×10^{-5} pCi/m³	4.4×10^{-6} pCi/m³
U-233/234	24-hour	6.4×10^{-8} pCi/m³	3.0×10^{-9} pCi/m³
U-235	24-hour	2.2×10^{-8} pCi/m³	1.0×10^{-9} pCi/m³
U-238	24-hour	9.1×10^{-8} pCi/m³	4.2×10^{-9} pCi/m³

Notes:
Am = americium
pCi/m³ = picocuries per cubic meter
PM_{10} = particulate matter less than 10 micrometers
Pu = plutonium
U = uranium
μg/m³ = micrograms per cubic meter

Fine Particulate Matter (PM_{10}) Concentration

The highest estimated 24-hour impact of PM_{10} for the 903 Pad high wind event was 0.004 μg/m³. This impact was estimated to occur at the receptor representing the S-107 sampler, which is located approximately 200 m east of the 903 Pad. This estimated maximum 24-hour impact, when combined with a background PM_{10} concentration of 87 μg/m³, would be well below the 24-hour NAAQS for PM_{10} of 150.0 μg/m³. Figure C2-13 shows an isopleth plot for the maximum estimated 24-hour PM_{10} impacts.

Pu-239/240 Concentration and Deposition

The maximum estimated 24-hour concentration of Pu-239/240 for the 903 Pad high wind event was 4.6×10^{-4} pCi/m³. As with PM_{10}, the highest estimated impact was predicted to occur at the receptor representing the S-107 sampler. Figure C2-14 shows the distribution of 24-hour concentration estimates for Pu-239/240 for the high wind simulation.

Figure C2-15 shows the distribution of estimated 24-hour dry deposition of Pu-239/240 in pCi/m²/yr. As shown in Figure C2-15, maximum deposition was predicted to occur in the direction of the predominant winds during the period.

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Am-241 Concentration and Deposition

The maximum 24-hour concentration of Am-241 was also estimated to occur at the S-107 sampler location. The maximum estimated 24-hour impact was 9.6×10^{-5} pCi/m^3. Figure C2-16 shows the distribution of 24-hour concentration estimates for Am-241.

Figure C2-17 shows the distribution of estimated annual dry deposition of Am-241 in pCi/m^2/yr. The distribution of deposition follows a similar pattern to the pattern displayed by Pu-239/240, but with a lower magnitude.

Uranium U-233/234, U-235, and U-238 Concentrations and Deposition

Borehole soil concentrations of uranium in 903 Pad Cell Strip 1 were used to convert particulate emissions to uranium emissions. The Cell Strip 1 borehole concentrations for uranium are three orders of magnitude lower than the concentrations of Pu-239/240 and Am-241. Consequently, the maximum estimated 24-hour concentrations of uranium isotopes were much lower than for Pu-239/240 or Am-241. The maximum 24-hour impact for U-238 was estimated to be 9.1×10^{-8} pCi/m^3, and predicted 24-hour impacts for the other uranium isotopes were even lower. For each uranium isotope, the maximum impacts were predicted to occur at the receptor representing sampler S-107. Estimated 24-hour deposition of the uranium isotopes was also of a much lower magnitude than for Pu-239/240 or Am-241.

3.3 Conclusions

The results of the 903 Pad remediation scenario modeling indicated that annual average PM_{10} and actinide concentrations would be well within applicable standards for a remediation project conducted according to the assumptions made here. Use of additional fugitive dust control measures, such as a weather enclosure, would further lessen ambient concentrations of both particulate matter and actinides. Deposition of actinides to ground or surface water would also be reduced.

Conversely, excavation of larger amounts of contaminated soil would increase airborne actinides and actinide deposition. Cleanup to more restrictive levels, such as removal of all soils contaminated at or above Tier II levels, for example, would result in excavation of additional soil, thereby increasing airborne actinide concentrations and deposition.

Maximum actinide and PM_{10} concentrations during remediation would occur at or very near the remediation site, with high PM_{10} levels also occurring along the route traversed by haul trucks leaving or entering the Site. Airborne concentrations of dust and actinides would decrease with distance from the work area because most of the emissions would occur near ground level and would not be buoyant.

The annual distribution of both concentration and deposition impacts showed higher impacts to the east-southeast and to the south of the work area than in other directions (see, for example, Figures C2-11 and C2-12 in Appendix C2). The patterns reflect a number of different factors. Wind-dependent emissions from storage piles and bare ground would occur at all hours of the day and reflect the prevailing wind speed/wind direction distribution. The component to the south, in contrast, reflects dispersion from activities that occur during the workday. Prevailing daytime winds show a greater frequency of north to south wind flow than night winds or the annual average wind distribution.

The high wind event showed much lower maximum impacts than the annual remediation scenario. While most results are not directly comparable because of the difference in averaging times (24-hour vs. annual), 24-hour PM_{10} concentrations were calculated for both scenarios and offer a direct comparison (see Figures C2-1 and C2-13 in Appendix C2 and Tables 3-3 and 3-5). The reduced impacts during high winds are due to two factors, described below.

First, during high winds, wind speed dependent emissions, such as wind erosion of bare ground surfaces and storage piles, would increase and emission control by water spray would be ineffective. However, other emission sources such as excavation and traffic would not emit during high winds. The net result is a smaller total increase in emissions than might otherwise be expected or even a net decrease.

Second, dispersion is increased during high winds. Airborne dust and actinide concentrations are a function not only of emissions but also of the dispersive capability of the atmosphere. However, although the maximum impact will decrease in high winds, the emissions will be spread over a larger area. The trade-offs that occur as wind speed increases are explored in more detail in Section 7.2 of this report.

4.0 SCENARIO 3: DECONTAMINATION AND DECOMMISSIONING

The preferred alternative for the near- and long-term management of facilities at the Site is decommissioning. Decommissioning involves decontamination and demolition of each building cluster at the Site. While this alternative will maintain long-term protection of public health and the environment, it also has the potential for short-term environmental and public health impacts if not performed carefully. Although the plans and protocols for building demolition at the Site call for only "clean" demolition (demolition of facilities that meet criteria for unrestricted release off Site), a hypothetical demolition scenario was modeled that assumed that a pocket of contamination would escape detection and be released during building demolition.

4.1 Scenario Description

Facility demolition at the Site will involve large mechanical equipment, which could include a wrecking ball/crane, excavator-mounted attachments (pulverizers, shears, grapples, and rams), and/or front-end loaders, all of which have significant dust generation potential. Prior to any facility demolition, a pre-demolition survey is conducted to determine the nature and extent of radiological contamination. Once it is determined that the facility meets unrestricted release criteria, demolition activities can be planned and initiated.

Scenario 3 assumed that a pre-demolition survey would be conducted that would indicate that a building cluster meets the Site unrestricted release criteria. However, contamination was assumed to be present in a fissure in a concrete wall that the survey could not detect. During the demolition process, the contamination would be released into the environment as particulate emissions (concrete dust).

4.2 Emission Estimation

To determine the amount and impact of contamination released, the following assumptions were made:

- The contamination would consist of weapons-grade plutonium (including americium ingrowth);
- The contamination would occur in a 20-foot (ft) (6.1-m) long, 10-cm deep fissure in a concrete wall, penetrating the concrete to a depth of 1 centimeter (cm);
- The contamination level would be 1 million disintegrations per minute per 100 square centimeters (dpm/100 cm^2);

- Contamination would be released as particulate matter (PM) during demolition of the concrete wall, or during size reduction of the concrete;

- The release time was assumed to be 1 hour and would occur in the vicinity of the Solar Ponds (see Figure 1-2); and

- The release would be a one-time occurrence with a total activity of 1.1×10^{-5} pCi.

Radionuclide emissions were calculated as detailed in Appendix D1 to this report.

4.3 Modeling Methods

The emissions from Scenario 3 were modeled as a volume source with the ISCST3 model. It was assumed that the release would form an initial plume with a cubic shape with a length on each side of 3 m. Volume source release parameters were determined in accordance with recommendations in the *User's Guide For The Industrial Source Complex (ISC3) Dispersion Models, Volume I – User Instructions* (EPA, 1995a). Release height for the volume source was set at ground level. Details of the model input calculations are described in Appendix D2.

Meteorological input to the ISCST3 model consisted of the on-Site 1996 meteorological data file that was used for FY99 modeling and for modeling several other FY00 scenarios. One-hour estimates of Pu-239/240 and Am-241 concentrations were obtained with ISCST3. The FY00 receptor grid described in Section 2.3.2 was used.

4.4 Modeling Results

This section presents the results of Scenario 3.

Plutonium (Pu-239/240) Concentration

The estimated maximum 1-hour concentration of Pu-239/240 was highest at the modeling receptor closest to the release point. The maximum estimated 1-hour impact for Pu-239/240 was 0.62 pCi/m^3. Off-Site impacts would be much lower. Figure D2-1 presents an isopleth plot of the estimated 1-hour concentration distribution for Pu-239/240.

Americium (Am-241) Concentration

The maximum 1-hour concentration for Am-241 was also estimated to be highest at the modeling receptor closest to the release point. The maximum estimated 1-hour impact for Am-241 was 0.06 pCi/m^3. Again, concentrations at the Site fenceline would be much

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lower. Figure D2-2 presents an isopleth plot of the estimated 1-hour concentration distribution for Am-241.

4.5 Conclusions

The D&D modeling analysis indicated that release of a highly contaminated pocket of concrete during demolition could result in relatively high but short-lived airborne actinide concentrations. The maximum impacts would occur very close to the release point. Concentrations at the facility fenceline would be several orders of magnitude less.

5.0 SCENARIO 4: FIRE/POST-FIRE

Another natural resuspension mechanism is the release of actinides contained in vegetation or attached to vegetation surfaces that would occur when the vegetation is burned. Fires may be planned (prescribed burns) or unplanned. Unplanned fires may occur at the Site due to lightening strikes, as occurred as recently as July 2000, or due to ignition of flammable vegetation by other means. This scenario explores a reasonable worst-case situation in which a fire begins in a period of maximum fuel load and minimum post-fire recovery potential on an area with significant actinide contamination.

The 903 Pad area was again chosen as the modeling location for this scenario. Wildfires resulting from presumed lightning strikes were modeled under two discrete sets of assumptions, from which short-term (i.e., fire-released) and longer-term (i.e., exposed soil erosion) actinide resuspension was estimated. Actinide release rates remained a function of particulate emission rates, but through different mechanisms than discussed in previous sections of this report.

The particulate and actinide emissions of the wildfire events and post-fire resuspension were estimated as described below and detailed in Appendix E1.

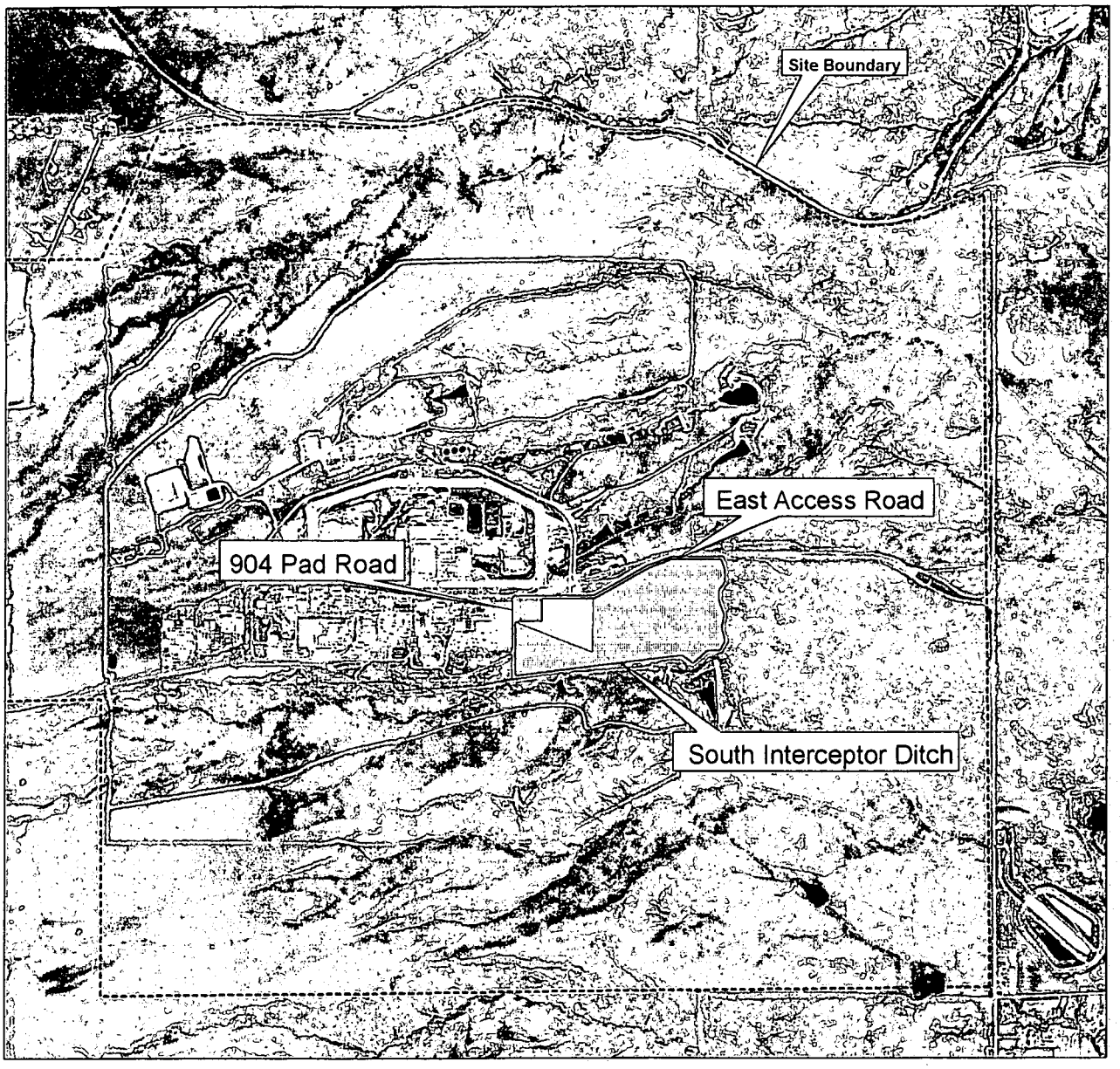
5.1 Wildfire Scenario

This section discusses the emissions and associated air impacts from hypothetical wildfires at the Site. A post-fire wind erosion scenario is discussed in Section 5.2.

5.1.1 Scenario Description

Two temporal alternatives were explored in this scenario. First, a wildfire occurring in the 903 Pad area in its current, pre-remediation condition was modeled under varying westerly wind speeds. Next, a post-remediation, post-closure wildfire in the 903 Pad area was modeled under varying westerly wind speeds. Both fires were modeled as having occurred in late September of a very dry year, when maximum fuel load would be present.

The modeled fires were assumed to be ignited by lightning striking near the 903 Pad itself. The fires were assumed to move east across the Pad Field and downslope to the South Interceptor Ditch (SID), pushed by westerly winds. As shown in Figure 5-1, the fires were assumed to consume an area bounded by the SID to the south, the 904 Pad road to the west, the East Access road to the north, and a fenceline to the distant east, where the fires were assumed to be stopped by emergency responders. The area was divided into a high actinide concentration area and a low actinide concentration area, based on the actinide concentrations in the surface soil. For modeling purposes, the areas were assumed to burn concurrently.



N

LEGEND

Facility Boundary

903 Pad

High Concentration

Low Concentration

Fire Boundary

0.5 0 0.5 1 1.5 Kilometers

NOTE:
Coordinates reference
UTM Meters, Zone 13, NAD27

Figure 5-1. Fire/Post-Fire Scenario: Area Used to Model Wildfire

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

APPLICATION	DATE	DR. BY
fig5-1.apr	09/26/2000	dc

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5.1.2 Emission Estimation

Federal land management agencies, including the U.S. Forest Service (USFS) and the Bureau of Land Management (BLM), have studied fire emissions extensively and have developed a variety of tools to estimate particulate emissions and dispersion from fires. The EPA has also published particulate matter emission factors for fires in *Compilation of Air Pollutant Emission Factors* (AP-42) (EPA, 1995b). USFS and BLM models were used extensively to estimate particulate emissions for these wildfire scenarios.

Particulate Emission Estimates

Particulate emissions from fires vary with the fuel type (e.g., grass, shrubs, trees, etc.) and with the fuel loading (the mass of fuel per unit area). The nature and amounts of pollutants are thought to be directly related to the intensity and direction (relative to the wind) of a wildfire, and indirectly related to the rate at which the fire spreads. The latter may be influenced by a variety of variables, including the weather, fuel parameters, and topography (EPA, 1995b). The following sections identify the particulate emission factors employed and the key characteristics of the fires that were modeled which, when combined, yielded the estimated particulate emissions.

Particulate Emission Factors

Smoke from fires is a complex mixture of carbon, tars, liquids, and gases. This open combustion source produces particles of widely ranging size, depending to some extent on the rate of energy release of the fire. Particulate emissions from fires have been estimated by a number of researchers. Emission factors vary depending on the fuel type, the rate of energy release (fire intensity), and the various fire phases (flaming, glowing, smoldering, etc.).

For this study, emission factors were taken from Leenhouts (1998), as shown in Table E1-1 of Appendix E1. These factors have been used in a recent update to the BLM's Simple Approach Smoke Estimation Model (SASEM) (Sestak and Riebau, 1988), and are specific to western perennial grassland fires.

Fuel Loading and Consumption Factors

Fuel loading may be expressed in several ways—as the mass of combustible material that will be consumed in a wildfire under specific weather conditions (available fuel), as the mass of all combustible material that would burn under the most severe weather and burning conditions (total fuel), or as the amount of larger, woody material that would remain even after an intense fire (potential fuel). For this study, empirically determined

vegetation mass values from various locations on Site were employed (available fuel), as detailed in Appendix E1, Table E1-2.

Leenhouts included in his emission factors values for the proportion of available fuel that will be consumed in a fire. For standing grasses, he estimated that 50% will be consumed. For litter, the consumed proportion is 90 percent. In general, wildfires at the Site would be expected to consume grass and grass-derived ground litter in these proportions.

Fire Duration Factors

For any wildfire scenario, burn duration may be estimated based on the area assumed to burn, characteristics of the fuel and fire, and weather conditions. For the modeled wildfire scenarios, the burn duration was determined through the use of a fire behavior model (Andrews and Bevins, 1998). Based on a range of potential wind speeds ranging from 1 m/s to 20 m/s, the entire 109 acre area could take from 3.3 hours (minimal winds) to only 9 minutes (sustained winds over 15 m/s) to burn completely, as detailed in Appendix E1.

Actinide Emission Estimates

Actinide emissions from a wildfire are a function of the amount and size of particulate released during the fire; however, the amount of contaminated soil on the vegetation that is burned, the activity in that soil and, depending on isotope, the amount of actinide taken up by vegetation make estimating actinide emissions from fire more complicated than estimating actinide emissions from wind erosion of soil reservoirs. The wildfire particulate emission estimating methods discussed above do not differentiate between soil-derived and plant-derived particulates.

Standing grasses and litter were assumed to have surface-attached soil particles, as discussed in the FY99 air pathway report (Radian, 1999). These soil particles were assumed to be released when the grasses and litter burned. Soil isopleths were used to determine the radioactivity of attached soil particles; radioisotopes were assumed to be present in the same concentration in the attached soil particles as in the surrounding soil.

A portion of the activity in the root zone soil was also assumed to be incorporated in plant tissue and, therefore, in the ash remaining after combustion. Soil isopleths were used to convert mass particulate emissions to activity units for various isotopes of interest, subject to the variables described below and in Appendix E1.

Figure 5-1 illustrates the split of the 109 acre burn plot, based on soil isopleths, into a high actinide concentration area and a low actinide concentration area. These areas were assumed to burn concurrently for modeling purposes. While their particulate emission

rates ($g/m^2/s$) are identical, their actinide emission rates ($pCi/m^2/s$) differ dramatically due to differences in the average soil activity.

Mass Loading

How much soil is attached to vegetation surfaces? Pinder et al. (1989) summarized the results of their own studies and those of other researchers and reported that soil attachment ranges from 1.4 milligrams soil per gram vegetation (mg/g) to 250 mg/g, dry weight basis. Soil attachment varies with plant type—broadleaved plants carry more soil than narrow-leaved plants, while shorter plants carry more soil per unit weight than taller plants, which include the weight of cleaner, upper portions of the vegetation. An average value for soil attachment obtained from measurements on and near the Site was reported by Arthur and Alldredge (1982) as 44 mg soil/g plant material during autumn months. This average value plus one standard deviation (giving a total soil loading of 134 mg/g) was used as a reasonable worst-case single value for fire scenario vegetation during a late September wildfire. For this short-term scenario, all actinides were assumed to be attached to the PM_{10} fraction of emitted particulates and deposition was not considered, as detailed in Appendix E1.

Dilution of Activity

Measurements at the Site suggest that the activity in soil attached to vegetation surfaces may be reduced relative to the underlying soil activity due to the deposition of less contaminated soil particles derived from "upwind" sources. This issue has also been explored conceptually in the development of DOE's RESRAD risk assessment model (Chang et al., 1998; Gilbert et al., 1983). Generally the RESRAD developers and their colleagues have assumed that the mass loading of particulates in air downwind from a radiologically contaminated soil area will include both contaminated particles originating from the finite contaminated area and "clean" particles originating from an infinite surrounding area of uncontaminated soil. The proportion of contaminated to clean particles will decrease in proportion to the size of the contaminated area and with distance downwind from the contamination. On a theoretical basis, they have concluded that directly above the contaminated area, the proportion of contaminated particles to clean would range from negligible to perhaps a 50/50 mix (Gilbert et al., 1983). At most points downwind, the proportion should be less.

Based on the above data and inference, use of the underlying soil activity to represent the activity of soil on vegetation surfaces is probably a reasonable upper bound across the Site. Use of a diluted activity may be warranted if use of the conservative upper-bound values appears to yield unreasonably conservative overestimates of emissions. However, no such adjustment was made in the modeling reported here.

Plant Uptake

A transfer coefficient approach is used in risk assessment models to account for plant uptake of actinides, where the transfer coefficient expresses the elemental concentration of a given isotope in vegetation dry weight relative to the elemental concentration of the isotope in the root zone soil (for example, pCi/g plant mass divided by pCi/g soil). Baes et al. (1984) estimated average transfer coefficients for both vegetative and reproductive plant tissues for elements of interest:

- Plutonium isotopes: 4.5×10^{-4} (vegetative), 4.5×10^{-5} (reproductive);
- Americium isotopes: 0.0055 (vegetative), 2.5×10^{-4} (reproductive); and
- Uranium isotopes: 0.0085 (vegetative), 0.004 (reproductive).

These transfer coefficients were used to convert particulate emissions from plant combustion into actinide emissions from radionuclides contained in plant tissue, based on the soil concentrations of actinides in the root zone soil. As with attached-soil particulate emissions, all plant uptake-derived actinide emissions were assumed to be inhalable (attached to or contained in the PM_{10} fraction). Appendix E1 provides additional detail on estimates of actinide release from this source.

5.1.3 Modeling Methods

This section describes the modeling methodology for the wildfire simulation. ISCST3 was used to simulate dispersion, using the receptor grid shown in Figure 2-2. Particulate and actinide concentrations were calculated during the fire events but deposition of particulates to ground or water surfaces was not simulated as part of this short-term event. Pu-239/240 and Am-241, the primary radiological contaminants in the assumed wildfire area, were modeled but uranium isotopes were not. Additional technical details are presented in Appendix E2.

Emission Source Locations

Because the area selected for the simulated wildfire includes the 903 Pad, the fire was modeled for two configurations that differed according to the status of the pad. One configuration simulated the current conditions at the Site, with the 903 Pad covered in asphalt and not available as fuel for a wildfire. The other configuration was the post-closure condition in which the 903 Pad was assumed to be unpaved and revegetated. In this post-closure condition, the surface of the former 903 Pad would provide potential fuel for a wildfire.

For each configuration, the total area for the burn was divided into two smaller areas, one with a higher average soil contamination level (under or near the 903 Pad), and the other with a lower average soil concentration level. Each source area was digitized and a series

of points was determined that created multi-sided polygons to approximate each area's shape. The multi-sided polygons were input to the ISCST3 model as area sources. The average contamination levels for Pu-239/240 and Am-241 within each area were determined by examining the surface soil activity maps described in Section 2.2.2. Emissions of Pu-239/240 and Am-241 were determined by combining the soil activity levels with particulate (PM_{10}) emissions, the amount of soil attached to ash, and transfer coefficients for the actinides of interest (described in Section 5.1.1 and Appendix E1).

Meteorological Input

Although a wildfire in the selected area was estimated to burn between 9 minutes and 3.3 hours, depending on wind speed, each wildfire configuration was modeled as a 1-hour event with the ISCST3 model. To simulate the full spectrum of meteorological conditions that could influence dispersion of pollutants from the fire, the combinations of wind speed and atmospheric stability that are used in EPA's SCREEN3 model were used for the fire modeling (EPA, 1995c). The SCREEN3 model is used to provide straightforward estimates of dispersion by applying a full range of meteorological conditions and identifying the condition that yields the highest results. The meteorological combinations include hourly wind speeds ranging from 1.0 m/s to 20.0 m/s, and atmospheric stability classes ranging from very unstable conditions to stable conditions. Ordinarily, the SCREEN3 meteorological combinations include a constant hourly temperature of 293K (20°Celsius [C]). For the purposes of the simulated wildfire, the temperature for each SCREEN3 meteorological combination was changed to 299.8K, which is the ambient temperature (26.8°C) at which the fire was assumed to begin. The SCREEN3 meteorological combinations were converted to an input file suitable for the ISCST3 model, with a constant wind direction for each hour that represented winds blowing from west to east across the burn area (i.e., toward the nearest fenceline).

Source Characteristics

Each emission source area (high concentration area and low concentration area) was modeled as a ground-based area source in ISCST3, with an initial vertical dimension that was based on the expected height of the smoke plume. The height of the smoke plume from a fire is a complex function of wind speed, stability, size and shape of the burn, and fuel characteristics. The height of the plume was calculated for each source area using equations from the SASEM model (Sestak and Riebau, 1988), for each wind speed and stability combination in the meteorological data, as described in Appendix E2. The initial vertical dimension of each area source was set to the plume rise divided by 2.15, as recommended in the ISCST3 user's guide (EPA, 1995a).

5.1.4 Modeling Results

This section describes the results of the wildfire simulations. Maximum on-Site and off-Site impacts for both wildfire scenarios are summarized in Table 5-1.

Table 5-1. Results Summary—Wildfire Scenarios

Pollutant	Averaging Period	Maximum Concentration	
		On Site	Off Site
Pre-Closure Configuration			
PM_{10}	1-hour	6.528 µg/m³	6,208 µg/m³
Pu-239/240	1-hour	0.15 pCi/m³	0.12 pCi/m³
Am-241	1-hour	0.06 pCi/m³	0.05 pCi/m³
Post-Closure Configuration			
PM_{10}	1-hour	7,364 pCi/m³	6,213 pCi/m³
Pu-239/240	1-hour	0.17 pCi/m³	0.17 pCi/m³
Am-241	1-hour	0.05 pCi/m³	0.05 pCi/m³

Notes:
Am = americium
pCi/m³ = picocuries per cubic meter
PM_{10} = particulate matter less than 10 micrometers
Pu = plutonium
µg/m³ = micrograms per cubic meter

Fine Particulate Matter (PM_{10}) Concentrations

The maximum 1-hour concentration of PM_{10} for a wildfire under pre-closure conditions (i.e., excluding the 903 Pad as a source area) was estimated to be 6,527.5 µg/m³. This impact was estimated to occur approximately 1 km east of the 903 Pad, with a meteorological combination that included a very light wind speed (1.0 m/s) and a stable atmosphere. The maximum estimated 1-hour impact at the RFETS fenceline was 6,207.8 µg/m³. These impacts represent the concentrations within the wildfire plume. Figure E2-1 shows the distribution of estimated 1-hour concentrations of PM_{10} for the pre-closure configuration.

Concentrations were not modeled for periods longer than 1 hour for the fire scenarios. However, it is clear that during a wildfire event with the characteristics that were assumed for this simulation, 24-hour average PM_{10} concentrations could be well in excess of the NAAQS level of 150 µg/m³. Assuming the worst-case impacts from a 3-hour fire were averaged over a 24-hour period, the concentrations in the vicinity of the plume would exceed 750 µg/m³ at the fenceline (i.e., 6,207.8 µg/m³ x 3/24 = 775.9 µg/m³), without any consideration of other contributing sources of PM_{10}. (It should be noted that the 24-hour

PM_{10} standard allows for occasional exceedances of the regulated level from just such an unavoidable circumstance as a wildfire.)

For the post-closure configuration that includes the area of the pad within the wildfire, the maximum 1-hour concentration of PM_{10} was estimated to be 7,364.3 $\mu g/m^3$. This impact was estimated to occur at the same location as the maximum impact for the pre-closure configuration, with the same meteorological combination that included a very light wind speed (1.0 m/s) and a stable atmosphere. The maximum estimated 1-hour impact at the RFETS fenceline was 6,213.1 $\mu g/m^3$. Figure E2-2 shows the distribution of estimated 1-hour concentrations of PM_{10} for the post-closure configuration. Twenty-four hour concentrations for the post-closure scenario could also exceed the NAAQS.

Predicted post-closure impacts were higher than pre-closure impacts because the total area that was assumed to burn was larger. Under the pre-closure scenario, the 903 Pad itself does not represent an area of available fuel. Remediation and revegetation of this area will increase the total fuel available in a wildfire in this portion of the Site.

Plutonium (Pu-239/240) Concentration

The maximum 1-hour concentration of Pu-239/240 in the pre-closure wildfire configuration was estimated to be 0.15 pCi/m^3. This impact was estimated to occur approximately 0.5 km east of the 903 Pad, and again would occur with a meteorological combination of a very light wind speed (1.0 m/s) and a stable atmosphere. The maximum estimated 1-hour impact at the RFETS fenceline was 0.12 pCi/m^3. Figure E2-3 shows the distribution of estimated 1-hour concentrations of Pu-239/240 for the pre-closure configuration wildfire.

For the post-closure configuration, the maximum 1-hour concentration of Pu-239/240 was estimated to be 0.17 pCi/m^3. This impact was estimated to occur approximately 2.5 km east of the 903 Pad at the RFETS fenceline, under a very light wind (1.0 m/s) and a stable atmosphere. Figure E2-4 shows the distribution of estimated 1-hour concentrations of Pu-239/240 for the post-closure configuration wildfire.

Again, predicted post-closure impacts were higher than estimated pre-closure impacts. Not only would the remediated/revegetated 903 Pad area increase available fuel for a fire, it would also increase the amount of actinides available for resuspension. The actinides will occur in dust on vegetation surfaces and in small amounts in plant tissues. Although the soils underlying the 903 Pad will be remediated, some residual actinide contamination would remain that would increase the total amount of actinides that could be resuspended during a wildfire in this area. This pattern holds for Am-241, as well, as described below.

Americium (Am-241) Concentration

The maximum 1-hour concentration of Am-241 in the pre-closure configuration was estimated to be 0.06 pCi/m^3. This impact was estimated to occur approximately 0.5 km east of the 903 Pad, with a meteorological combination that included a very light wind speed (1.0 m/s) and a stable atmosphere. The maximum estimated 1-hour impact at the RFETS fenceline was 0.05 pCi/m^3. Figure E2-5 shows the distribution of estimated 1-hour concentrations of Am-241 for the pre-closure configuration wildfire.

For the post-closure configuration, the maximum 1-hour concentration of Am-241 was estimated to be 0.05 pCi/m^3. This impact was estimated to occur approximately 2.5 km east of the 903 Pad at the RFETS fenceline, under a light wind speed (1.0 m/s) and a stable atmosphere. Figure E2-6 shows the distribution of estimated 1-hour concentrations of activity for Am-241 for the post-closure configuration wildfire.

5.2 Post-Fire Scenarios

The release of actinides during a wildfire is of concern because a fire generates high levels of particulate matter emissions. Actinides on or in vegetation may be released in the wildfire plume. A second concern is the denudation of contaminated areas by wildfires. The bare ground may be subject to disturbance and wind erosion until the vegetative canopy recovers. This second situation was the subject of several post-fire resuspension scenarios, as described below. Additional technical details of the emission calculations and the modeling results are presented in Appendices E1 and E2.

5.2.1 Scenario Description

Annual plutonium and americium concentrations due to resuspension of contaminated soil and ash from the burned area were estimated for the post-fire scenarios. As described below, the actual rate of recovery after a wildfire will depend on various factors such as the time of year that the fire occurs, the fire intensity, and the amount and frequency of rainfall occurring after the fire. Scenarios were modeled representing gradual recovery from wildfires assuming both pre-closure and post-closure contaminant levels, as described in Section 5.1.1.

Though vegetation density may return to its pre-burned state in a matter of weeks under optimal conditions, as observed following the April 2000 Site test burn, it may take up to a full year or more for vegetation to recover under extremely dry conditions. The hypothetical burn area is primarily vegetated with cool season grasses. Depending on the intensity of the wildfire, plant shoots and roots could be destroyed and soil may be sterilized to some extent, factors that would further retard the regrowth of vegetation. In general, though, there will be some green-up of grasses throughout the ensuing months, regardless of whether they are cool or warm season species. The recovery of vegetation

and the restabilization of emission potential following a fire both vary with the fire's intensity. If it is a "cool" burn, as is the goal during a prescribed fire, native vegetation is usually regenerated. If it is a "hot" burn, as is common with wildfires, plant shoots and roots can be destroyed, inhibiting plant regrowth. The amount of litter affects the temperature of the fire, with more litter contributing to a hotter fire. If the fire occurs during a given plant's primary growing season (i.e., it occurs during the spring for a cool-season plant), then that plant's regrowth potential is hindered because the fire occurred during its peak period of growth and reproduction. The occurrence of rainfall, relative to the time of the fire, also significantly affects the recovery rate, with the occurrence of rain fostering plant regrowth.

Immediately following the hypothetical fire, the ground surface was assumed to be bare soil overlain with ash and interspersed with stubble left from incomplete combustion of plant material. The ash left by the fire was assumed to be more readily resuspended than either bare soil particles or dust adhering to vegetation because of its lower density and larger surface area. However, the resuspension rate of ash immediately following a fire and how that rate changes with time have not been documented to any great extent in the literature.

As described in Section 1.4, a test burn was conducted over a 50-acre area of the Site in April 2000 in preparation for future prescribed burns. Conditions during and after the burn were ideal for regrowth of the native vegetation. Wind tunnel testing was conducted to characterize the influence of the burn on soil erosion potential. A "control" test was conducted over an area adjacent to the burn to provide a base case for comparison. Two days after the prescribed burn, the first post-burn wind tunnel test was conducted. This "immediate" post-burn test was delayed until two days after the fire because a period of high winds followed the fire, precluding field testing during that time. Consequently, the actual immediate post-fire resuspension rate is expected to have been higher than that observed during the first post-burn test. Additional tests were conducted 4 weeks and 10 weeks after the prescribed burn to characterize the change in soil erosion potential as a function of vegetation recovery.

By the time of the second post-burn wind tunnel test (four weeks later), the prescribed burn plot was qualitatively observed to be about one-half of the way back to a fully vegetated state. The particulate (PM_{10}) concentration recorded in the wind tunnel at this time (and hence the soil resuspension rate) was approximately halfway between that observed during the control test and that observed during the immediate post-burn test.

Final data from these experiments are not yet available, but preliminary observations were used in preparing the post-fire scenarios that were modeled. Wind tunnel data will be available in Fall 2000 and will be used to fine-tune the post-fire scenario assumptions. The post-fire scenarios will be re-modeled in FY01 using this additional information.

5.2.2 Emission Estimation

The mechanism for resuspension of soil particles and, thereby, actinides from the burned area following a wildfire is essentially the same as that for chronic soil resuspension, described in Section 2.0. The significant difference is the assumed increased rate of surface erosion and particulate emissions from unprotected (unvegetated) soil. Multipliers were developed and applied to the resuspension equation that was described in Section 2.2.1 to estimate post-burn particulate emissions, and the resulting actinide release was calculated as a function of the particulate emission rate.

Post-Fire Particulate Emissions

The various stages that would occur in the vegetative recovery process following a wildfire are described in Table 5-2. To address post-fire particulate emission estimation in light of the limited data available, a simple multiplier approach was adopted. These multipliers are shown in Table 5-2 and were applied to the original (chronic) wind speed-dependent emission estimation equation described in Section 2.2.1. The time spans shown relate to a hypothetical wildfire occurrence in late September.

Table 5-2. Hypothetical Stages of Post-Fire Surface Recovery—Case 1

Stage	Surface Description	Multiplier	Time Span
1	Primarily exposed soil surface, with ash deposits and stubble	10	1 week post fire (7 days)
2	Primarily exposed soil with surface crusting, ash removed and stubble remaining, and some initial regrowth of vegetation	6	October through mid-February (145 days)
3	Primarily exposed soil with surface crusting and increased regrowth of vegetation	3	March through May (92 days)
4	Mostly revegetated surface, with some exposed soil areas	2	June through September (122 days)
5	Completely revegetated surface	1	—

Notes:
— = not applicable

Wind tunnel data obtained from the OU3 site to the east of RFETS were used to select the 10-times multiplier for the immediate post-burn period (EG&G, 1994). While the data were not collected under post-fire conditions, they do reflect resuspension from a soil area that was highly disturbed, and should give some indication as to an upper bound of resuspension for the immediate post-burn period. During the OU3 study, representative

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surface areas were "disturbed" by cutting the vegetation at ground level. The exposed surface was raked and driven over to pulverize the remaining material to a depth of at least 1 inch (EG&G, 1994). Data from this study indicate that the resuspension flux from these "extra disturbed" soil areas, for a given wind speed, would be approximately 10 times that obtained from the original (chronic) emission estimation equation (which was also derived from OU3 wind tunnel data).

The six-times multiplier shown in Table 5-2 came from preliminary observations made during and after the April 2000 test burn. The particulate concentration obtained from wind tunnel tests increased to six times the control (pre-burn) level in tests conducted after the burn. However, as previously mentioned, two days of high winds had occurred just after the burn, presumably removing much of the ash material. The wind tunnel particulate concentration six weeks after the burn was only three times the control level. The two-times multiplier shown in the table was chosen based on the other multipliers.

It should be noted that although there would be regrowth of vegetation during the first growing season, it would take at least one complete growing cycle to reestablish the litter layer (in terms of soil surface area protected from wind). The bare soil area underlying new vegetation would not be covered up until winter weather arrives, when snow and wind would knock over and mat down the standing dead plant material. One season's growth, however, would not cover all the exposed soil between plants.

Conceptually, the presence of bare soil between plants should enhance the overall resuspension potential, as the bare areas should facilitate the transfer of soil particles onto plant surfaces by mechanisms such as rainsplash, in addition to providing a direct source for soil resuspension. Conversely, it would take some time for the new vegetation to accumulate attached soil particles to the extent that pre-fire vegetation was dust laden. It is unclear how to account for this conflict in natural processes.

Given the uncertainty in the characterization of the recovery process, two cases were identified for modeling, to see what affect variation in the time span would have on the annual average concentration and deposition predictions. The alternate case selected for modeling is defined in Table 5-3. This case reflects a much quicker recovery rate, with pre-burn resuspension rates reestablished by the following July.

Post-Fire Actinide Emissions

Post-fire actinide release from the exposed soil reservoir would be a function of particulate emission rates. As described for the chronic resuspension and remediation scenarios (Section 2.0 and 3.0), the activity of individual isotopes in the 903 Pad area soils (pCi/g) was multiplied by the mass resuspension rate of soil in $g/m^2/s$, yielding $pCi/m^2/s$ of resuspension for each actinide of interest.

To assess the potential influence of post-fire resuspension rates on concentrations and dose, a comparison study was performed. The acreage in question was initially modeled with the wind-driven resuspension equation identified in Section 2.2.1 without applying any multipliers. In other words, the impacts due to plutonium and americium activity

Table 5-3. Hypothetical Stages of Post-Fire Surface Recovery—Case 2

Stage	Surface Description	Multiplier	Time Span
1	Primarily exposed soil surface, with ash deposits and stubble	10	3 days post-fire
2	Primarily exposed soil with surface crusting, ash removed and stubble remaining, and some initial regrowth of vegetation	6	October through November (58 days)
3	Primarily exposed soil with surface crusting and continued initial regrowth of vegetation	3	December through February (91 days)
4	Mostly revegetated surface, with some exposed soil areas	2	March through June (122 days)
5	Completely revegetated surface	1	—

Notes:
— = not applicable

resuspension, assuming no influence of fire, were determined from this limited area. For this "base case," the particle size distribution and plutonium activity distribution identified in Table 2-1 were used. No adjustments for periods of snow cover were made for any of the model runs for consistency with the reasonable worst-case assumptions (i.e., a very dry year following the wildfire).

The acreage in question was then modeled using the multiplier-adjusted particulate and actinide emissions (as identified in Tables 5-2 and 5-3). The particle size distribution and activity distribution were also revised for the post-fire model runs, as described in Section 5.2.3. The impacts from the post-fire runs were compared to the paired base case results to determine the affect of enhanced post-fire resuspension on annual Pu-239/240 and Am-241 concentrations and EDE.

5.2.3 Modeling Methods

For the post-fire scenario, actinide concentrations (Pu-239/240 and Am-241) resulting from resuspension from an area recovering from a wildfire were estimated and compared to resuspension impacts from the same area in an undisturbed state. As with the wildfire modeling described in Section 5.1.3, the post-fire scenario was modeled for two

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configurations that differed according to the status of the 903 Pad. One configuration excluded the area of the 903 Pad because it was assumed to be in a pre-closure state (paved and not available as fuel for a wildfire or for resuspension following a wildfire). The other configuration was the post-closure condition for which the 903 Pad area would be unpaved, revegetated, and provide available fuel for a wildfire. The post-fire recovery modeling was further separated into two cases that represented two different rates of vegetation recovery, as identified in Tables 5-2 and 5-3.

The total area to be modeled was divided into two areas, one with a higher average soil contamination level (under or near the 903 Pad), and the other with a lower average soil concentration level (see Figure 5-1). The emissions of Pu-239/240 and Am-241 were determined by multiplying the amount of resuspended particulate matter by the average soil activity level in either the low or high concentration area. The fire recovery emission rates were further adjusted by multiplying by the appropriate multipliers shown in Tables 5-2 and 5-3 for the two fire recovery scenarios.

Except as described below, the modeling methods were the same as those employed for the revised resuspension modeling described in Section 2.0. The ISCST3 model was employed with the receptor grid shown in Figure 2-2 and 1996 meteorological data. Resuspension was simulated using ground-based area sources. Concentrations were calculated and included the effects of particle settling on plume depletion; however, deposition was not calculated.

For the undisturbed case, the source variables for particle size categories, mass fractions, particle density, and activity fractions were the same as used for other resuspension modeling at the Site (Table 2-1). This allowed for proper accounting of plume depletion for the modeling of the undisturbed case. For the fire recovery modeling, the plume depletion parameters were taken from soil aggregation/disaggregation research conducted using Site soils (Ranville et al., 2000).

The soil disaggregation research reported by Ranville et al. (2000) was conducted to determine the effect that a fire might have on soil particles at the Site and the distribution of activity on those particles. Specifically, the effect of a fire was simulated by disaggregating soil with hydrogen peroxide (H_2O_2), which destroys the organic fraction of the soil that acts as a glue to create aggregates. The result was a shift in mass to smaller size fractions and a much more dramatic shift to smaller size fractions for Pu-239/240 activity. Although, as discussed previously, what becomes airborne may not precisely match the distribution in the surface soil, the overall trend in the particle size/activity distribution in the disaggregated soil should be reflected in the airborne particulate matter.

The particle size categories and plutonium activity fractions (also applied to Am-241) from the Ranville et al. research are shown in Table 5-4. Mean particle diameters were calculated with the equation presented in Section 2.3.2.

As initially modeled, the fire recovery scenarios included ash resuspension as a separate source. It was assumed that ash would be present over the entire burn area for either three days (Case 1 recovery) or seven days (Case 2 recovery) immediately after the fire.

Table 5-4. Particle Size Data Used for Fire Recovery Dispersion Modeling

Particle Size Category	Lower-Upper Bound for Particle Size Category (μm)	Mean Diameter for Particle Size Category (μm)	Particle Density (g/cm^3)[a]	Plutonium Activity Fraction[b]
1	1-2	1.6	2.65	0.35
2	2-10	6.8	2.65	0.42
3	10-25	18.5	2.65	0.07
4	25-53	40.5	1.8	0.04
5	53-200	138.7	1.8	0.08
6	200-2,000	1,295.6	1.6	0.04

[a] Foster et al., 1985.
[b] Ranville et al., 2000.
Notes:
μm = micrometers
g/cm^3 = grams per cubic centimeter

Ash has a lower density than ordinary soil particles, which would affect both resuspension and plume depletion. However, it was suspected that the fleeting presence of ash sources would not contribute significantly to estimated impacts over an annual period. This was confirmed through a sensitivity study which varied the density of the ash sources from 1.6 g/cm^3 to 0.15 g/cm^3 (the lowest value revealed by a literature search; Baxter, 2000). The difference in the maximum estimated annual impact for the range of particle densities was only 0.2 percent. Therefore, for the final modeling, the ash sources were modeled with the particle size categories and particle densities that were used for regular soil particles (Table 5-4). The enhanced resuspension over the life of the ash sources was accounted for through the recovery rate multipliers (Tables 5-2 and 5-3).

5.2.4 Modeling Results

This section presents the results of the post-fire resuspension modeling. Pre- and post-burn impacts are summarized in Table 5-5.

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Table 5-5. Results Summary—Post-Fire Recovery Scenarios

Isotope	Maximum Estimated Annual Concentration (pCi/m^3)[a]		Factor for Conversion of pCi/m^3 to mrem	Maximum Estimated Annual EDE (mrem)	
	On Site	Off Site		On Site	Off Site
Pre-Closure Base Case					
Pu-239/240	7.3×10^{-4}	4.7×10^{-6}	5,000	3.7	0.02
Am-241	2.9×10^{-4}	1.5×10^{-6}	5,263	1.5	0.008
Pre-Closure Case 1 Fire Recovery					
Pu-239/240	3.5×10^{-3}	2.3×10^{-5}	5,000	17.5	0.1
Am-241	1.4×10^{-3}	7.4×10^{-6}	5,263	7.4	0.04
Pre-Closure Case 2 Fire Recovery					
Pu-239/240	2.2×10^{-3}	1.5×10^{-5}	5,000	11.0	0.08
Am-241	8.9×10^{-4}	4.7×10^{-6}	5,263	4.7	0.03
Post-Closure Base Case					
Pu-239/240	1.0×10^{-3}	6.8×10^{-6}	5,000	5.0	0.03
Am-241	2.9×10^{-4}	1.8×10^{-6}	5,263	1.5	0.01
Post-Closure Case 1 Fire Recovery					
Pu-239/240	5.0×10^{-3}	3.3×10^{-5}	5,000	25.0	0.2
Am-241	1.4×10^{-3}	8.7×10^{-6}	5,263	7.4	0.05
Post-Closure Case 2 Fire Recovery					
Pu-239/240	3.2×10^{-3}	2.1×10^{-5}	5,000	16.0	0.1
Am-241	9.2×10^{-4}	5.6×10^{-6}	5,263	4.8	0.03

Notes:
Am = americium
mrem = millirem
pCi/m^3 = picocuries per cubic meter
Pu = plutonium

Plutonium (Pu-239/240) Concentrations for Pre-Closure Fire Scenarios

The first pre-closure modeling scenario was designed to predict Pu-239/240 concentrations due to resuspension from the area of the wildfire in a pre-burn, undisturbed state. The results of this base case model run were compared to the results of the fire recovery modeling. Figure E2-7 shows the estimated annual Pu-239/240 concentration distribution for the pre-burn scenario. A maximum annual concentration of 7.3×10^{-4} pCi/m^3 was estimated to occur approximately 200 m east-southeast of the 903 Pad. At the RFETS fenceline, the maximum estimated annual concentration was 4.7×10^{-6} pCi/m^3.

Figure E2-8 shows the estimated annual Pu-239/240 concentrations for the Case 1 fire recovery scenario. This scenario was designed to estimate the annual Pu-239/240 concentration distribution for resuspension from a surface that is undergoing recovery from a wildfire. The modeled area was the same as the area modeled for the undisturbed

state, but with emissions altered to reflect enhanced resuspension (Table 5-2) and the particle characteristics from Table 5-4. A maximum annual Pu-239/240 concentration of 3.5×10^{-3} pCi/m^3 was estimated to occur at the same location as the maximum for the pre-burn scenario. The predicted post-burn maximum impact was approximately five times higher than the pre-burn base case impact. The maximum annual Case 1 Pu-239/240 concentration at the RFETS fenceline was estimated to be 2.3×10^{-5} pCi/m^3.

The maximum estimated annual Pu-239/240 concentration for the Case 2 recovery scenario was 2.2×10^{-3} pCi/m^3. The Case 2 maximum was also predicted to occur at the same location as the pre-burn and Case 1 maximums. At the RFETS fenceline, the maximum estimated annual Pu-239/240 concentration from Case 2 was 1.5×10^{-5} pCi/m^3. The lower magnitude for the Case 2 estimated impacts was due to the faster recovery rate assumed than that simulated for Case 1. The faster recovery rate would lead to faster vegetation growth and lower levels of resuspension when compared to Case 1. Case 2 results are shown in Figure E2-9.

Americium (Am-241) Concentrations for Pre-Closure Fire Scenarios

Figure E2-10 shows the estimated annual concentration of Am-241 for the pre-burn scenario. As with Pu-239/240, the maximum annual concentration of Am-241 of 2.9×10^{-4} pCi/m^3 was estimated to occur approximately 200 m east-southeast of the 903 Pad. At the RFETS fenceline, the estimated maximum annual Am-241 concentration would be 1.5×10^{-6} pCi/m^3.

Figure E2-11 shows the estimated annual Am-241 concentration for the Case 1 fire recovery scenario. The maximum annual Am-241 concentration of 1.4×10^{-3} pCi/m^3 was estimated to occur at the same location as the maximum for the pre-burn scenario. The predicted post-burn maximum impact was approximately five times higher than the maximum impact for the pre-burn base case. The maximum annual Case 1 Am-241 concentration at the RFETS fenceline was estimated to be 7.4×10^{-6} pCi/m^3.

The maximum estimated annual Am-241 concentration for the Case 2 recovery scenario was 8.9×10^{-4} pCi/m^3. The Case 2 maximum was also predicted to occur at the same location as the pre-burn and Case 1 maximums. At the RFETS fenceline, the maximum estimated annual Am-241 concentration from Case 2 was 4.7×10^{-6} pCi/m^3. Figure E2-12 shows the estimated annual Am-241 concentrations for the Case 2 fire recovery scenario. Again, the lower magnitude for the Case 2 estimated impacts was due to the faster assumed recovery rate of vegetation compared to Case 1.

Plutonium (Pu-239/240) Concentrations for Post-Closure Fire Scenarios

The post-closure modeling scenarios were designed to predict Pu-239/240 concentrations for the same sequence of model runs used for the pre-closure configuration, but with area

source extents and soil concentrations that reflected the expected post-closure state of the Site. Figure E2-13 shows the estimated annual concentration of Pu-239/240 for the pre-burn, undisturbed base case scenario. The maximum annual Pu-239/240 concentration of 1.0×10^{-3} pCi/m^3 was estimated to occur approximately 200 m east-southeast of the 903 Pad. At the RFETS fenceline, the estimated maximum annual Pu-239/240 concentration was 6.8×10^{-6} pCi/m^3.

Figure E2-14 shows the estimated annual Pu-239/240 concentration for the Case 1 fire recovery scenario. The maximum annual Pu-239/240 concentration of 5.0×10^{-3} pCi/m^3 was estimated to occur at the same location as the maximum for the pre-burn scenario and was approximately five times higher than the maximum for the pre-burn case. The maximum estimated annual Pu-239/240 concentration at the RFETS fenceline for Case 1 was 3.3×10^{-5} pCi/m^3.

The maximum estimated annual Pu-239/240 concentration for the Case 2 recovery scenario was 3.2×10^{-3} pCi/m^3. Case 2 impacts are shown in Figure E2-15. The Case 2 maximum was also predicted to occur at the same location as the pre-burn and Case 1 maximums. At the RFETS fenceline, the maximum estimated Pu-239/240 concentration for Case 2 was 2.1×10^{-5} pCi/m^3. As with the pre-closure model runs, the lower magnitude for the post-closure Case 2 estimated impacts was due to the faster vegetation recovery rate than is simulated for Case 1.

The estimated maximum Pu-239/240 impacts for the post-closure, post-fire scenario were approximately 40% higher than the estimated impacts for the pre-closure runs. This is primarily due to the additional slightly contaminated soil (at or below the Tier I soil action level) that will be available for wind erosion when the paved surface over the 903 Pad is removed.

Americium (Am-241) Concentrations for Post-Closure Fire Scenarios

Figure E2-16 shows the estimated annual concentration of Am-241 for the pre-burn base case scenario. As with Pu-239/240, the maximum annual concentration of Am-241 of 2.9×10^{-4} pCi/m^3 was estimated to occur approximately 200 m east-southeast of the 903 Pad. At the RFETS fenceline, the estimated maximum annual Am-241 concentration was 1.8×10^{-6} pCi/m^3.

Figure E2-17 shows the estimated annual Am-241 concentration for the Case 1 fire recovery scenario. The maximum annual Am-241 concentration of 1.4×10^{-3} pCi/m^3 was estimated to occur at the same location as the maximum for the pre-burn scenario and was approximately five times higher than the maximum for the pre-burn base case. The maximum annual Am-241 concentration at the RFETS fenceline for Case 1 was estimated to be 8.7×10^{-6} pCi/m^3.

Figure E2-18 shows the estimated annual Am-241 concentration for the Case 2 fire recovery scenario. The maximum estimated annual Am-241 concentration for the Case 2 recovery scenario was 9.2×10^{-4} pCi/m^3. The Case 2 maximum was also predicted to occur at the same location as the pre-burn and Case 1 maximums. At the RFETS fenceline, the maximum estimated annual Am-241 concentration for Case 2 was 5.6×10^{-6} pCi/m^3.

The estimated impacts for the Am-241 post-closure runs were very similar to the estimated impacts for pre-closure runs because the modeled soil Am-241 concentrations were the same for pre-closure and post-closure. Although the removal of the paved areas over 903 Pad for post-closure will expose areas with higher Am-241 soil activity concentrations, the post-closure scenario assumed that high Am-241 concentration areas would have been remediated to much lower levels of contamination (see description in Section 6.0 of this report). Therefore, the average soil Am-241 levels in the area of the simulated wildfire were estimated to be the same for the pre-closure and post-closure configurations.

Although soil Am-241 concentrations were the same, the estimated impacts for post-closure runs were slightly higher than pre-closure runs because of the larger size of the high concentration area source for the two cases. For the post-closure runs, the area of the 903 Pad was added to the high concentration area source, while for the pre-closure runs the 903 Pad was excluded.

5.3 Conclusions

Both fire scenarios (pre-closure and post-closure contaminant levels) show high particulate matter concentrations within the plume, but for a relatively short period of time (fire durations of between 9 minutes and 3.3 hours were estimated). The maximum PM_{10} concentrations predicted (less than 7,000 μg/m^3) were comparable to those measured by researchers in forest fire plumes (Ward, 1999) and could potentially result in 24-hour average concentrations in excess of NAAQS levels. Maximum PM_{10} and actinide concentrations would occur under low wind speed, stable conditions, which would inhibit plume dispersion.

The post-closure fire would produce slightly higher particulate and actinide concentrations than the pre-closure fire. The 903 Pad is not currently a source of fuel or actinide emissions because it is paved. Cleanup would lower soil actinide levels but would also expose the soil under the pad. The area was assumed to revegetate; therefore, the 903 Pad area would represent an additional fuel and actinide source for the post-closure fire, which would increase impacts.

The post-fire resuspension scenarios showed that over the course of a year, a reasonable worst-case vegetation recovery scenario would result in a five-fold increase in actinide

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concentrations when compared to unburned conditions. The speed with which vegetative recovery would occur can affect the concentrations and resulting EDE substantially—the faster the recovery, the smaller the resulting increase in pollutant concentrations and EDE.

As with the fire scenarios, the post-closure vegetative recovery scenarios showed somewhat higher concentrations than the pre-closure scenarios. The reason is that the area of the 903 Pad itself would become a resuspension source after the asphalt covering is removed.

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6.0 SCENARIO 5: POST-CLOSURE CHRONIC RESUSPENSION

Scenario 5 was a revision of the natural resuspension modeling described in Section 2.0 (Scenario 1). Source inputs were revised to represent post-closure, open-space land use conditions at the Site. Specifically, this scenario represents cleanup of current soil contamination to the RFCA Surface Soil Action Levels that have been established for actinides at the Site. Post-closure conditions were assumed to include the removal of paved surfaces and building structures, especially in the Industrial Area, therefore allowing for wind erosion from all areas of the Site. This section describes the modeling approach used for Scenario 5, and the results of the modeling analysis.

6.1 Scenario Description and Emission Estimation

The goal of this modeling analysis was to estimate the annual dispersion and deposition of actinides from the resuspension of contaminated soil after closure of the Site. Closure of the Site will occur after the D&D of all existing structures that were associated with historical operation of RFETS. D&D will include the removal of pavement in the Industrial Area, thereby allowing for wind erosion and other natural resuspension mechanisms to act upon these formerly paved, nonerodible surfaces. Radioactive emissions to the atmosphere through natural resuspension under post-closure conditions will depend on the activity levels that remain in the soil.

Surface Soil Action Levels that have been established for Tier I, post-closure, open-space land use are shown in Table 6-1 (DOE et al., 1996). Tier I levels are based on an annual EDE limit of 85 mrem to a hypothetical future resident. The values shown in Table 6-1 were used to determine which sources that had been created for pre-closure resuspension modeling would be retained for post-closure modeling.

Table 6-1. Surface Soil Action Levels for Post-Closure

Radionuclide	Tier I Open-Space Land Use Level (pCi/g)
Pu-239/240	1,429
Am-241	215
U-233/234	1,738
U-235	135
U-238	586

Notes:
Am = americium
pCi/g = picocuries per gram
Pu = plutonium
U = uranium

Emissions for the post-closure scenario were estimated as described in Section 2.2 and Appendix B1.

6.2 Modeling Methods

The modeling assumptions and inputs for Scenario 5 were the same as those used for the revised natural resuspension modeling under current conditions (Scenario 1), with two primary exceptions. First, the area sources used to represent actinide emissions were expanded to include the areas that were considered nonerodible in Scenario 1, because these areas will be unpaved after closure of the Site. Second, area sources that represented emissions higher than the Surface Soil Action Levels shown in Table 6-1 were removed. Specifically, area sources for Am-241 representing activity levels of 250, 500, and 1,000 pCi/g were removed for the post-closure modeling because these sources were above the Tier I open-space cleanup level for Am-241 of 215 pCi/g.

No area sources were removed for Pu-239/240 because the Tier I open-space cleanup level is higher than any modeled soil activity contour for Pu-239/240. As with Am-241, however, the spatial extent of several Pu-239/240 area sources was expanded with the inclusion of the formerly nonerodible areas.

Another aspect of the post-closure configuration that was considered for modeling was the proposed "capping" of several areas in or near the Industrial Area. The "capping" would involve clean soil cover for the capped areas that would render the capped surfaces nonerodible from an actinide emission standpoint. Only one area planned for capping, the OU5 Landfill Area, affected the post-closure modeling. An area source that had been in place for pre-closure modeling of U-235 and another for U-238 were removed for Scenario 5 because they were located at the OU5 Landfill.

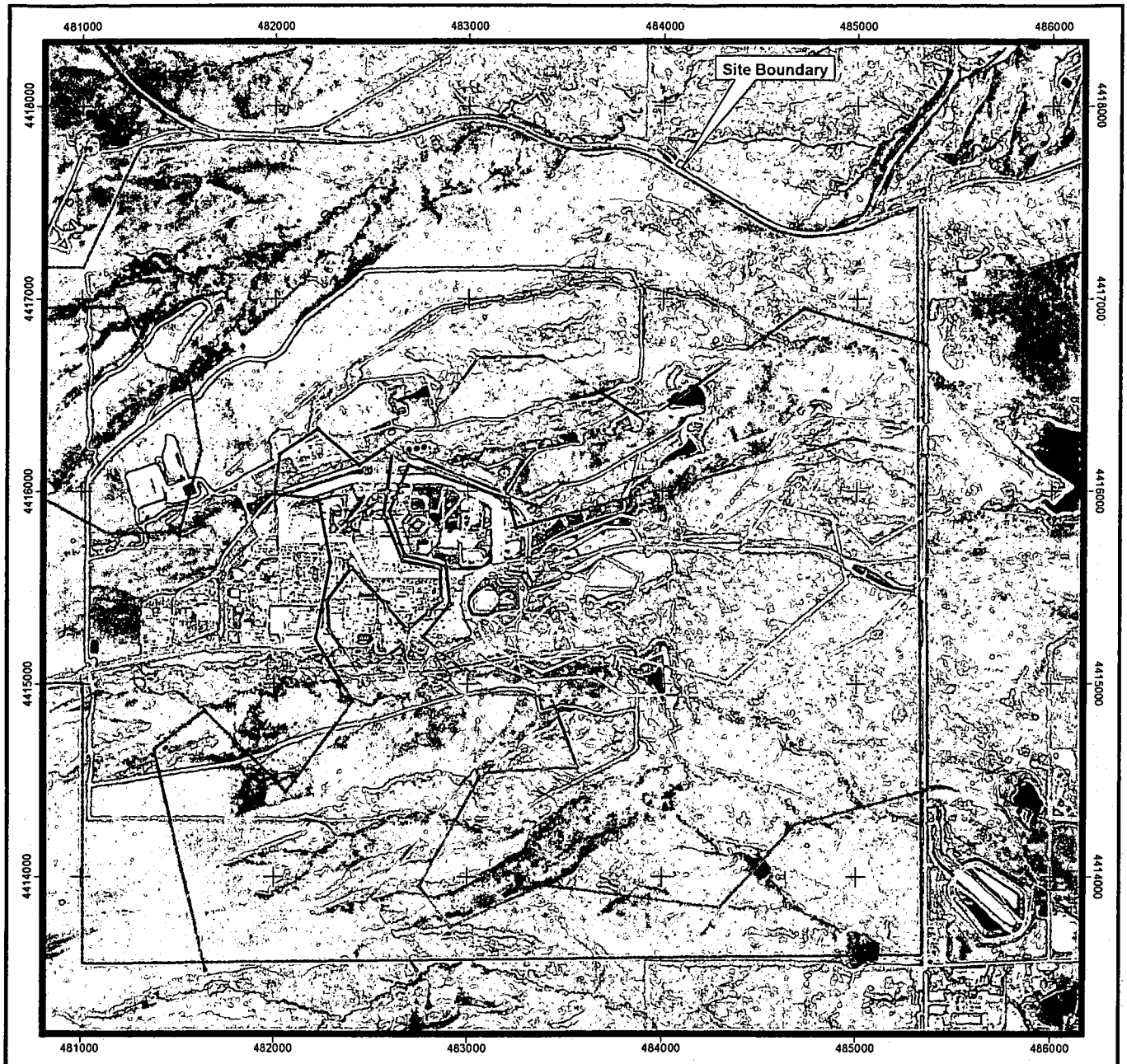
Figures 6-1 through 6-5 show the post-closure actinide isopleths that were used for modeling.

6.3 Modeling Results

This section presents the results of the post-closure modeling analysis. Maximum concentrations and EDEs are summarized for all actinides for the post-closure scenario in Table 6-2.

Plutonium (Pu-239/240) Concentration and Deposition

The estimated annual concentration of Pu-239/240 was highest near the northeast corner of the 903 Pad area. Figure F-1 presents an isopleth plot of the estimated annual concentration distribution for Pu-239/240 in units of pCi/m^3. When compared to Figure B-1, which showed the estimated concentrations for the pre-closure configuration, it is



Activity Level for
Pu-239 (pCi/g)

- 0.1
- 0.5
- 1.0
- 5.0
- 10.0
- 25.0
- 50.0
- 100.0
- 250.0
- 500.0
- 1000.0

N

0.5 0 0.5 1 1.5 Kilometers

NOTE:
Coordinates reference
UTM Meters, Zone 13, NAD27

Figure 6-1. Post-Closure: Surface Soil Contamination Isopleths Used for Model Input for Pu-239

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

APPLICATION	DATE	DR. BY
figsf_6.apr	09/26/2000	dc

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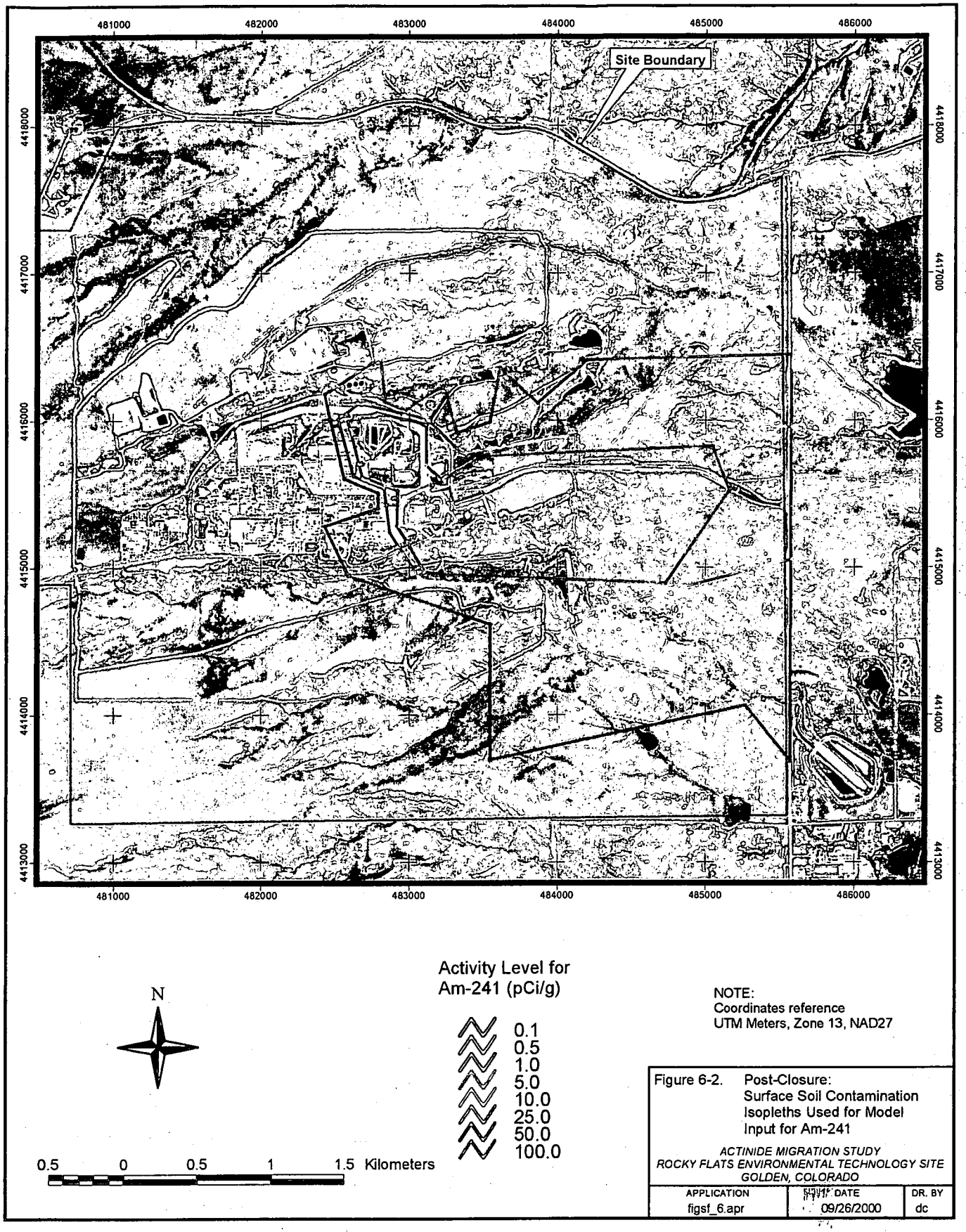

Figure 6-2. Post-Closure: Surface Soil Contamination Isopleths Used for Model Input for Am-241

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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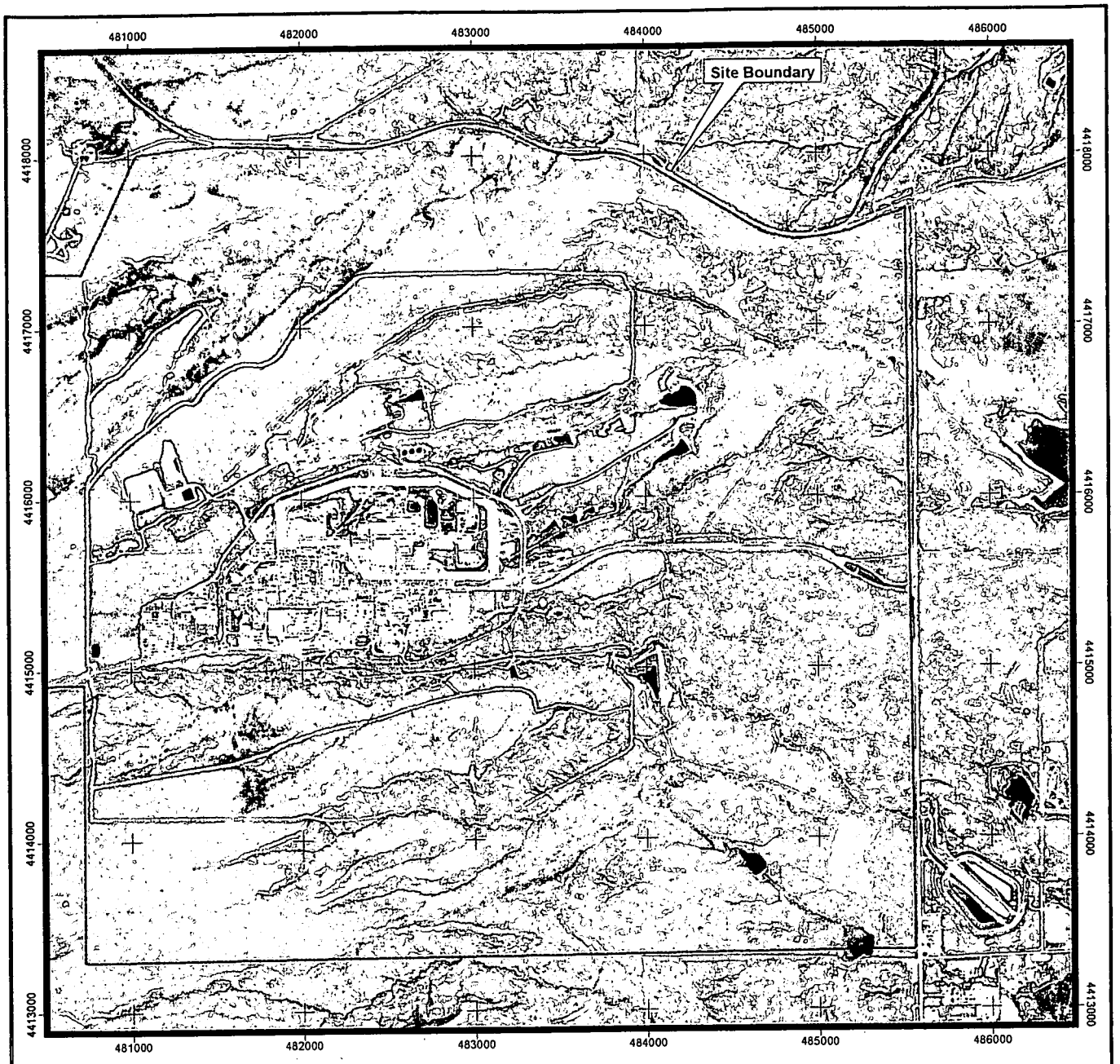

Activity Level for
U-233/234 (pCi/g)

5.0

N

NOTE:
Coordinates reference
UTM Meters, Zone 13, NAD27

0.5 0 0.5 1 1.5 Kilometers

Figure 6-3. Post-Closure:
Surface Soil Contamination
Isopleths Used for Model
Input for U-233/234

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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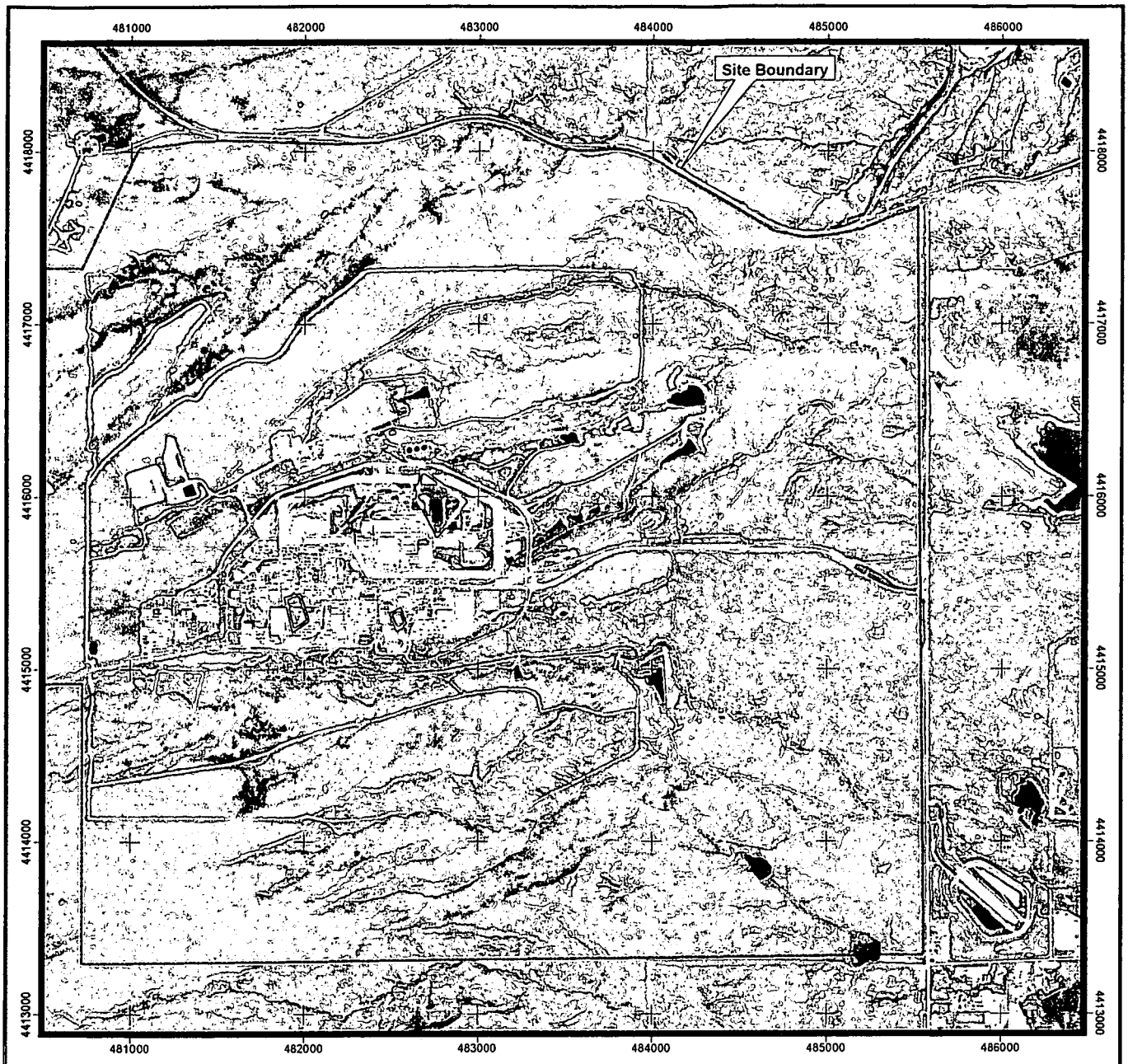

Activity Level for
U-235 (pCi/g)

1.0

NOTE:
Coordinates reference
UTM Meters, Zone 13, NAD27

N

0.5 0 0.5 1 1.5 Kilometers

Figure 6-4. Post-Closure: Surface Soil Contamination Isopleths Used for Model Input for U-235

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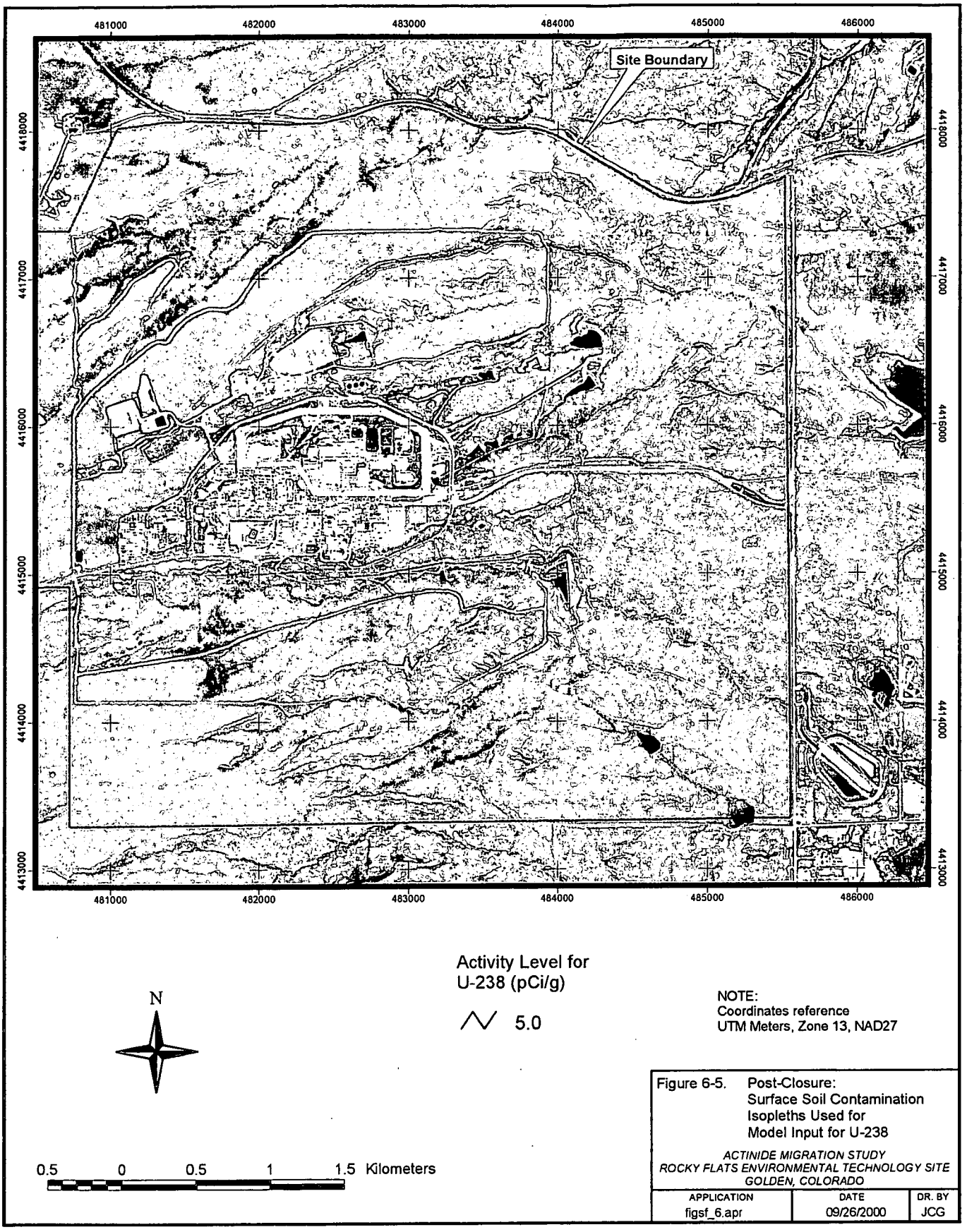

Figure 6-5. Post-Closure: Surface Soil Contamination Isopleths Used for Model Input for U-238

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Table 6-2. Results Summary—Post-Closure Chronic, Natural Resuspension Scenarios

Isotope	Maximum Estimated Annual Concentration (pCi/m^3)		Factor for Conversion of pCi/m^3 to mrem	Maximum Estimated Annual EDE (mrem)	
	On Site	Off Site		On Site	Off-Site
Pu-239/240	1.1×10^{-3}	2.0×10^{-5}	5,000	5.5	0.1
Am-241	1.6×10^{-4}	2.4×10^{-6}	5,263	0.9	0.01
U-233/234	2.2×10^{-7}	3.6×10^{-9}	1,299	2.9×10^{-4}	4.7×10^{-6}
U-235	2.8×10^{-7}	8.1×10^{-10}	1,408	3.9×10^{-4}	1.1×10^{-6}
U-238	1.2×10^{-5}	4.7×10^{-9}	1,205	0.02	5.7×10^{-6}

Notes:
Am = americium
mrem = millirem
pCi/m^3 = picocuries per cubic meter
Pu = plutonium
U = uranium

apparent that the predicted impacts for post-closure are of a greater magnitude, with the highest predicted impacts located nearer to the 903 Pad area.

The difference between the pre-closure and post-closure model runs can be explained by the additional sources that were included with the post-closure model run. These additional sources were added in the former Industrial Area, which had been treated as nonerodible (i.e., not a source of resuspension emissions) for the pre-closure analysis.

The additional post-closure sources with the highest actinide emissions were added in the immediate vicinity of the 903 Pad.

The far-field effects of the difference between the pre-closure and post-closure runs is shown through comparison of extent of a given isopleth in Figures B-1 and F-1. For example, for the post-closure run (Figure F-1), the 1.0×10^{-5} pCi/m^3 isopleth extends farther to the east past the facility boundary than the same isopleth does in Figure B-1, but only by a few hundred meters.

Figure F-2 shows the distribution of estimated annual dry deposition of Pu-239/240 in $pCi/m^2/yr$ for the post-closure configuration. As with the estimated Pu-239/240 concentration, the annual maximum is centered near the northeast corner of the 903 Pad. A comparison with Figure B-2 (pre-closure) shows that the post-closure scenario would yield comparable levels of deposition farther downwind than the pre-closure run.

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Americium (Am-241) Concentration and Deposition

The estimated annual concentration of Am-241 was also highest near the northeast corner of the 903 Pad. Figure F-3 presents an isopleth plot of the estimated annual concentration distribution for Am-241 in units of pCi/m^3. As with Pu-239/240, the estimated impacts for the post-closure modeling were of a greater magnitude than for the pre-closure run, with the highest predicted impacts located nearer to the 903 Pad. The difference between the pre-closure and post-closure runs can again be explained by the additional sources that were included in the post-closure scenario. Although several sources of Am-241 in the Industrial Area were eliminated from the post-closure modeling because they were above the applicable Surface Soil Action Level, other sources (formerly treated as nonerodible) were added from the same area. These additional sources brought about higher estimated impacts for the post-closure modeling.

Figure F-4 shows the distribution of estimated annual dry deposition of Am-241 in $pCi/m^2/yr$ for the post-closure configuration. As with the estimated Am-241 concentration, the annual predicted deposition maximum was centered near the northeast corner of the 903 Pad. A comparison with Figure B-4 (pre-closure) shows that the post-closure scenario yields a projected deposition pattern with a greater lateral and downwind extent.

Uranium U-233/234 Concentration and Deposition

The annual concentration of U-233/234 was estimated to reach a maximum at the northeast portion of the Industrial Area, near the lone U-233/234 activity contour (see Figure 6-3). The estimated post-closure impacts for U-233/234 were identical to the estimated impacts for pre-closure (described in Section 2.4) because the modeled source configuration for U-233/234 will not change with closure of the Site. Figure F-5 shows the estimated post-closure annual concentration distribution for U-233/234.

Figure F-6 shows the distribution of estimated annual dry deposition of U-233/234. The annual maximum was predicted to be centered near the northeast part of the Industrial Area.

Uranium U-235 Concentration and Deposition

The annual concentration of U-235 was estimated to reach a maximum level at the northeast, southwest, and south-central portions of the Industrial Area, as shown in Figure F-7. The locations of the maximum estimated impacts correspond to the locations of the U-235 activity contours shown previously in Figure 6-4. The estimated impacts in the southwest portion of the Industrial Area were less pronounced for the post-closure modeling than for the pre-closure case (Figure B-7) because the proposed capping of the OU5 Landfill removed an area source from consideration for the post-closure modeling.

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Figure F-8 shows the distribution of estimated annual dry deposition of U-235 in $pCi/m^2/yr$. Most predicted deposition is limited to the immediate vicinity of the Industrial Area.

Uranium U-238 Concentration and Deposition

The annual concentration of U-238 was estimated to reach a maximum level southwest of the Industrial Area, as shown in Figure F-9. The estimated impacts in the southwest portion of the Industrial Area were less pronounced for the post-closure modeling than for the pre-closure case (Figure B-9). This is because of the area sources that were removed from consideration for the post-closure modeling because of the proposed capping of the OU5 Landfill.

Figure F-10 shows the distribution of estimated annual dry deposition of U-238 in $pCi/m^2/yr$. The maximum estimated deposition was centered southwest of the Industrial Area. When compared to the pre-closure modeling (Figure B-10), the post-closure U-238 deposition pattern extends a lesser distance downwind and laterally because of the removal of sources under the post-closure configuration.

6.4 Conclusions

As with Scenario 1, maximum post-closure actinide concentrations and deposition would occur just to the east to slightly southeast of areas of surface soil contamination on Site. Based on the comparison of model results with sampling data (discussed in Section 2.5), maximum impacts are probably overestimated.

As was seen with the pre- and post-closure fire recovery scenarios, post-closure impacts would be slightly higher than pre-closure impacts. Maximum concentrations would increase by a factor of two to three over the pre-closure impacts. At the fenceline, the increase would be more limited—an increase of 15% is projected at the off-Site maximum impact point, while an average increase of 30% to 50% is projected along the eastern fenceline.

Remediation of the 903 Pad area and cleanup of soil contamination under buildings within the Industrial Area are important components of Site closure. Remediation projects will decrease actinide concentrations in Site soils, thereby decreasing the total actinides in the Site environment. However, removal of buildings and pavement will increase the soil surface areas available for wind erosion. Although only small amounts of actinides will be left in Site surface soils, particles and actinides will be resuspended from a significantly larger source area, with resulting increases in impacts to air from this small emission source. The maximum concentrations predicted would still be substantially less than the EPA air dose limit (10 mrem) and represent less than 2% of the average annual radiation dose received by residents of the Denver area.

7.0 OTHER INVESTIGATIONS

This section explores issues related to the scenario modeling presented in previous chapters of this report. First, concern has been expressed about the effects of high winds on resuspension of contaminated soils at the Site. Section 3.2 explored the effect that a high wind event would have during a remediation project. Section 7.1, below, explores the conflicting effects that increasing wind speeds have on emissions and dispersion in a more general manner.

Second, the post-closure scenario reported in Section 6.0 assumes that the Site will be dedicated to open space use. Under this assumption, soil disturbances would not occur, or at least not on a regular basis. Section 7.2 explores the effect that periodic disturbances would have on resuspension emissions and impacts to provide comparative data regarding possible non-open space scenarios.

Finally, as discussed in Section 1.1, the major patterns of soil contamination at the Site were established by various spills and releases that were subsequently acted upon by many years of wind resuspension and surface erosion effects. The possible effects of continued slow migration of contaminated soil from the Site due to wind erosion over hundreds to thousands of years is explored in Section 7.3.

7.1 High Wind Event

The Site is a windy place, even by Colorado standards. Fall, winter, and spring months typically exhibit several episodes of sustained high winds, where average wind speeds reach 30 to 45 mph over a period of hours. Gusts to near or above 100 mph are common during such events. As a result, one of the concerns regarding soil contamination at the Site is the increase in resuspension that can occur during such periods. Tornados, while uncommon, can also occur in the Denver area as a result of spring or summer thunderstorms. While resuspension occurs over the Site at a low rate even during modest winds, higher winds can resuspend much larger amounts of material and can scour bare or disturbed areas, producing a cloud of resuspended dust.

While higher winds will increase soil resuspension, they also result in better dispersion, which lowers pollutant concentrations. The purpose of this analysis was to explore the opposing effect of high winds on particulate emissions from resuspension and their subsequent dispersion.

7.1.1 Wind Speed and Modeling

Wind speed is used in dispersion modeling to determine plume rise (for point source emissions), plume dilution and, in the case of fugitive dust (suspension) and evaporation rate models, the mass transfer rate into the atmosphere. Gaussian models, such as the

ISCST3 model, are based on an assumption that concentration is inversely proportional to wind speed. As wind speed increases, plume rise decreases, plume dilution increases (due to increased entrainment of outside air), and the concentrations predicted by the dispersion model decrease. However, as wind speed increases, the resuspension of particulates also increases—as presented in Section 2.0, natural resuspension of soil on Site is a third-power function of wind speed.

A Gaussian screening model (SCREEN3; EPA, 1995c) was used to predict concentrations based on various wind speeds and the resuspension emissions associated with those wind speeds, based on the equation presented in Section 2.2.1. Figure 7-1 plots wind speed against emission rate and Figure 7-2 shows the relationship between modeled concentrations and wind speed. The estimates are based on a hypothetical area source of 100 square meter (m^2) area, and a wind speed range of 5 to 40 mph. The effects of higher wind speeds can generally be extrapolated from the graphs shown.

7.1.2 Discussion

Figure 7-2 shows the overriding influence of wind-driven emissions on the resulting concentrations. If the source emission rate were kept constant, concentrations predicted with the screening model would decrease with increasing wind speed. However, since emissions increase with the third power of wind speed, while concentrations decrease as only an inverse function of wind speed, the effect of wind speed on emissions has the greater influence.

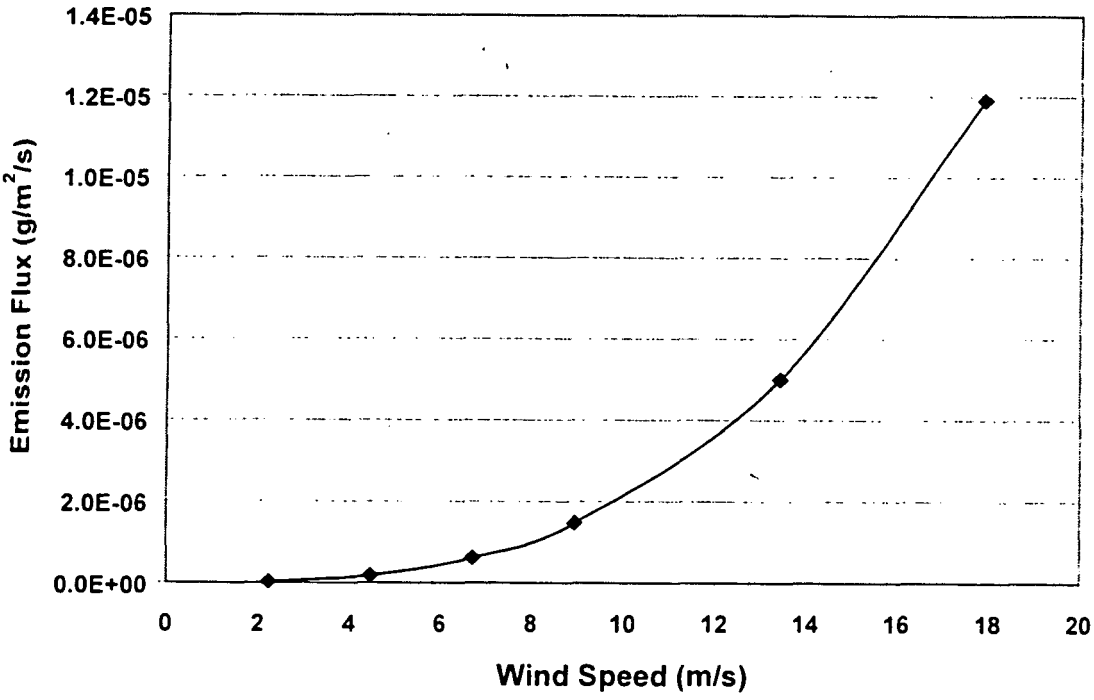

Figure 7-1. Relationship Between Particulate Resuspension Rate and Wind Speed

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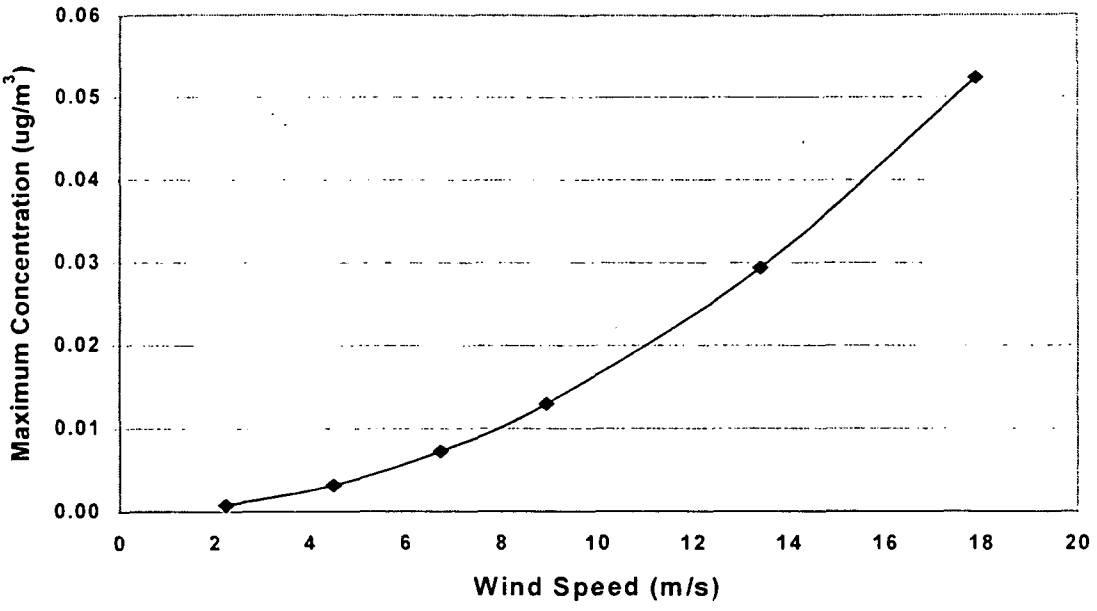

Figure 7-2. Relationship Between Airborne Concentration and Wind Speed

7.2 Periodic Disturbances

The expected use of the Site after closure is as open space. Under this scenario, the Site would be revegetated and would not be subjected to significant soil disturbance. As a result, resuspension of residual soil contamination would be minimized. Other possible uses of the Site have been proposed, however, and alternate uses could involve increased soil disturbance. The difference in impacts between the undisturbed scenario (Scenario 5, post-closure chronic resuspension) and other uses involving periodic soil disturbance is explored conceptually in this section.

7.2.1 Emission Estimation Method

The purpose of this analysis was to estimate the effect of periodic disturbances on particulate and actinide resuspension. Over time, a soil surface that remains undisturbed will show decreasing emissions as the erodible soil particles are removed and the surface develops a crust that inhibits further wind erosion. In addition, lack of disturbance will allow vegetation to cover the surface and lower the wind speeds to which the soil surface is exposed, further decreasing wind erosion.

A disturbance is an action that either renews or increases the available reservoir of erodible material (soil particles). A disturbance can take many forms, such as excavation, vehicular traffic, or that of a natural process such as a freeze/thaw cycle or rodent burrowing. The greater the disturbance, the longer it takes for the surface to be restored

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to an undisturbed state because the extent of disturbance affects the magnitude of the resulting reservoir of erodible particles. In addition, disturbances such as traffic or heavy equipment use can compact soil, which affects water infiltration and inhibits revegetation.

As discussed in Section 3.1, EPA has developed a method for estimating resuspension from soils with a limited reservoir of erodible material (EPA, 1988; EPA, 1995b). Soils covered with vegetation, rocks, or other nonerodible material have a limited reservoir of erodible particles. Soils with a tendency for crust formation, promoted by various factors including clay content in the soil, are also considered to have a limited reservoir of erodible material. Most soils at the Site will "crust" with time and exposure (Langer, 1986).

The equation (Limited Erosion Potential Model) given in Appendix C1 for estimating the erosion potential for any horizontal soil surface is:

$$P = 58(u^* - u_t)^2 + 25(u^* - u_t)$$ (AP-42, Section B.2.5.3 [1995])

where:

P is the erosion potential (g/m^2);
u^* is the friction velocity (m/s);
u_t is the threshold friction velocity (m/s);
58 is an empirical constant (unitless); and
25 is an empirical constant (unitless).

This equation yields the erosion potential between disturbance episodes. Hence, each time the soil is disturbed, an "emission event" occurs, resulting in the resuspension of soil to the atmosphere. The friction velocity used in the equation is based on the fastest mile wind speed, which is the meteorological variable best approximating the magnitude of wind gusts. Average winds are typically insufficient to sustain wind erosion from flat surfaces, but wind gusts may quickly erode a substantial portion of the erodible material (EPA, 1995b). The threshold friction velocity is a function of the particle size distribution of the soil.

The Limited Erosion Potential Model was used to illustrate the effect that periodic disturbances would have on soil resuspension. The worst-case friction velocity and threshold friction velocity values that were determined previously for Scenario 2 (903 Pad remediation) were retained for this analysis.

Other variables that can be applied to the equation (as multipliers) are the land area disturbed, the number of disturbances per year, and the percent of land area disturbed that is erodible. Introduction of these factors into the equation converts the soil erosion

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potential in units of mass per square area (e.g., g/m^2) to mass per year (e.g., g/yr). Further applying an average bulk soil density of 1.2 g/cm^3 (RMRS. 2000) and appropriate unit conversions produces an estimate of the effect of a disturbance in terms of cubic meters (m^3) of soil eroded by the wind over an annual period.

7.2.2 Results and Discussion

Table 7-1 shows the variation in amount of soil resuspended for differing areas and number of disturbances per year.

Table 7-1. Variations in the Estimated Amount of Soil Resuspended Annually by Surface Disturbance

Variable	Wind Erosion of Soil (m^3)
Percent of Site Surface Disturbed:[a]	
1	0.4
5	2.0
10	4.1
20	8.1
Number of Disturbances per Year:[b]	
4 (quarterly)	1.6
12 (monthly)	4.8
52 (weekly)	21.0

[a] Assumes area disturbed is 100% erodible material and is disturbed once annually.

[b] Assumes area disturbed is 100% erodible material, is disturbed once annually, and represents one percent of total Site area (approximately 65 acres).

The comparison illustrated in Table 7-1 reflects the linear relationships expressed by the Limited Erosion Potential Model. In other words, the amount of soil resuspended (and resulting downwind concentrations) is directly related to the frequency of disturbance and the size of the area disturbed. If the disturbed area is doubled, all other things being equal, the particulate concentration will double. Similarly, if the number of disturbances increases by an order of magnitude, the downwind impacts would increase by an order of magnitude. Overall, then, Site particulate emissions due to resuspension would increase under future scenarios involving soil disturbance in direct proportion to the frequency of disturbance and the extent of the surface area involved.

At the Site, this linear relationship holds for particulate emissions and downwind concentrations but cannot be directly related to actinide emissions and impacts. This is because another variable enters in—the concentration of actinides in the surface soil

(pCi/g) that is disturbed. While particulate emissions may double if the area disturbed is doubled, actinide emissions may increase either more or less than double, depending on how contaminated the additional disturbed area is.

Another factor that is extremely important in determining soil resuspension following disturbance is the timing of disturbances relative to high wind events. As noted previously, a disturbance results in a soil surface that is easily eroded by wind for some period of time. Over time, however, the surface weathers and crusts and erodibility is reduced. The occurrence of high winds during the period before the surface has crusted can result in much larger amounts of resuspension than the same winds would cause to a less disturbed surface. Much of the initial spread of contamination from the 903 Pad, for example, is thought to have resulted from a handful of windy days following grading or weed burning operations that disturbed the contaminated soil and exposed it to the full force of the wind (Weber et al., 1998).

An example of how wind-dependent emissions compare for disturbed and undisturbed ground is shown in Figure 7-3. The data in Figure 7-3 were taken from the OU3 wind tunnel study used to derive the Site-specific resuspension equation described in Section 2.2.1 The "extra disturbed" line represents ground surfaces that were raked and then driven over to break up clumps of soil. Figure 7-3 shows that the highly disturbed areas

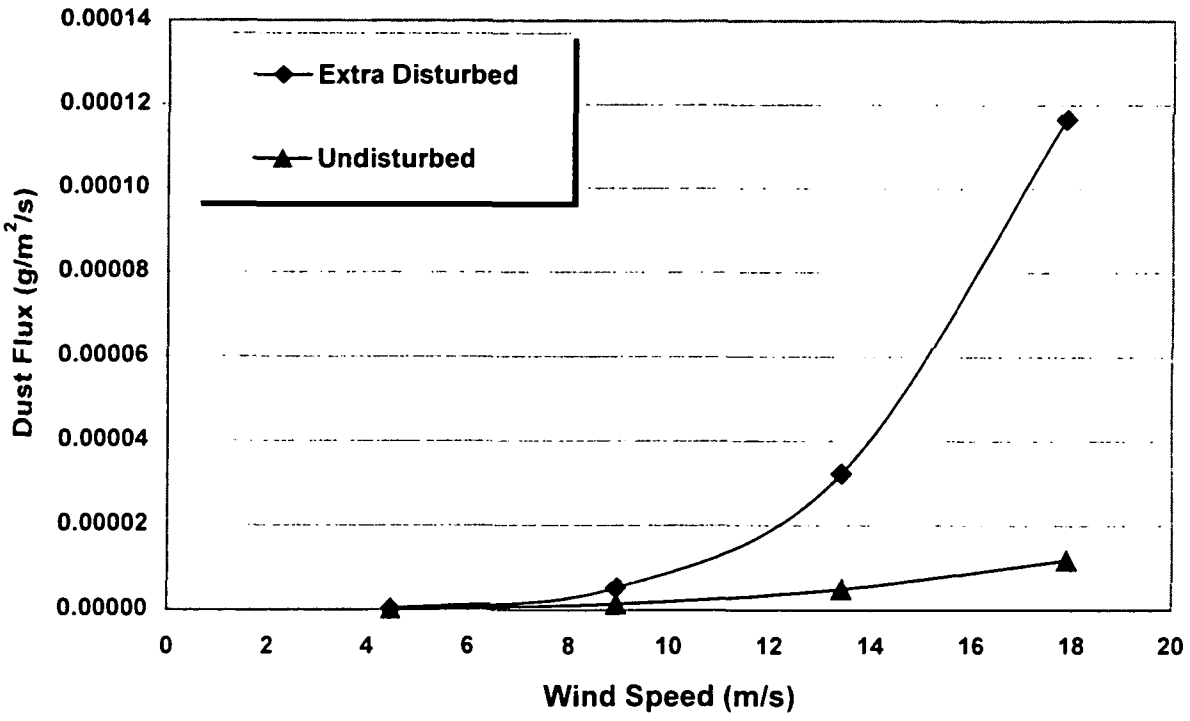

Figure 7-3. Emissions As a Function of Wind Speed

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resulted in enhanced resuspension at most wind speeds and that the difference in resuspension rate increased with increasing wind speed.

For comparison with the emission estimates provided by the Limited Erosion Potential Model, annual resuspension of particulates was also calculated using the emission estimation equation described in Scenario 1 (for undisturbed ground). The particulate flux was computed for each hour of the meteorological data modeled (1996), taking into account the influence of snow cover. Multiplying by a land area equal to one percent of the Site (approximately 65 acres), the empirically determined Site resuspension equation yields an annual resuspension estimate of 3 m^3 of soil. This represents somewhat higher particulate emissions than the Limited Erosion Potential Model for minimal disturbances (see Table 7-3).

As described in Section 2.5.2, the Site-specific emission estimation method appears to overpredict actinide concentrations in the predominant downwind directions. Possible contributing factors include both dilution of actinide concentrations in soil on vegetation surfaces relative to actinide concentrations in the underlying soil and a larger exponent in the emission estimation equation than is correct. The comparison of annual emission estimates based on the Site equation with the Limited Erosion Potential Model predictions suggests that at least part of the overprediction may be due to an overprediction of dust flux by the equation under high winds. As discussed in Section 1.4, wind tunnel work being performed in FY00 will add data and allow for refinement of the Site-specific equation.

7.3 Long-term Chronic Resuspension

Previous sections of this report have detailed the actinide concentrations and deposition that would occur due to various closure or post-closure activities or events. Impacts have been reported as the maximum that would occur anywhere (usually on Site) and also the maximum impacts that would occur at or beyond the Site fenceline. In the case of annual scenarios, maximum concentrations have also been reported in terms of effective dose equivalent (EDE).

In each case, the impacts reported have been those that would apply to a single individual, the so-called maximally exposed individual (MEI). DOE also uses an additional measure of dose, the collective or population dose. The collective dose (collective EDE) is the sum of the individual EDEs that would occur in a population exposed to radionuclide emissions from a source such as the Site. It is calculated by determining the annual radionuclide concentrations that would occur at various locations surrounding the source, converting those values to individual EDEs, and then multiplying those EDEs by the number of individuals presumed to be exposed to the same predicted radionuclide concentration. The collective dose is usually reported in units of person-rem, or person-rem per year (person-rem/yr) for an annual dose rate.

Although cleanup of the Site should result in a decrease in individual dose from all pathways, is it possible that the collective dose could increase with time as small amounts of actinides remaining in surface soils or waterways continue to migrate outward? Over a period of hundreds to thousands of years, this outward migration could be measureable. Consequently, one goal of the FY00 air pathway work was to investigate methods to estimate collective dose at some point in the distant future. The methods devised to calculate future collective dose are described below.

7.3.1 Current Contamination Pattern

As described in Section 1.1, surface soil actinide contamination at the Site is the result of leaks and spills of actinide-containing material over the years. The largest concentration of plutonium and americium in Site soils resulted from leaking drums at the 903 Pad. The existing Pu-239/240 and Am-241 contamination pattern for on-Site surface soils is shown in Figures 2-3 and 2-4 in Section 2.0 of this report.

Much of the existing contamination was probably deposited over a short time period when relatively large amounts of contaminated soil were redistributed in the environment. Drums were stored at the 903 Pad from July 1958 until June 1968, when the last drum was removed (ChemRisk, 1992). While soil contamination occurred during this period, the drums themselves served to limit wind erosion of the contaminated soils until removal began in January 1967.

Weber et al. (1998) examined the initial wind suspension of contaminated soil from the 903 Pad in detail, using air sampler measurement data to reconstruct the releases. They concluded that only 5% of the airborne plutonium emissions from the pad occurred from "baseline" releases between 1964 and 1969. Nearly all of the airborne emissions, representing between 10% and 30% of the total contamination that was deposited in the soil, were released during the 25 days when the nearby sampler showed the highest alpha counts (total emissions of approximately 3.1 Ci). Of this 25-day period, the highest six days accounted for approximately 90% of the total 1964 to 1969 airborne plutonium emissions (2.8 Ci) (Weber et al., 1998).

Examination of the six highest release days showed that most material was moved during high wind periods following recent soil disturbances. Activities that disturbed the contaminated soil and exposed it more directly to wind erosion, such as weed burning and grading, followed by high wind events, redistributed relatively large amounts of contamination in a short period of time.

7.3.2 Scenario Descriptions

Two scenarios were considered to explore projected collective dose at some point in the future. These scenarios are described below.

Stable Pattern Scenario

The fact that the present surface soil contamination patterns are largely the result of windblown suspension and subsequent deposition of the contaminated soil from the 903 Pad suggested one method of projecting collective dose at some point in the future. This first method assumed that the current contamination patterns are the result of a two-stage process. In the first stage, initial suspension and deposition of contaminated particles occurred primarily during a handful of windy days between drum removal and paving of the 903 Pad. In the second stage, the initial contamination pattern, now protected and stabilized by vegetation cover, was acted upon by approximately 30 years of ambient wind and weather, resulting in a time-integrated pattern that reflects the continuing processes that redistribute soil and contamination in the Site environment.

The degree to which continued wind erosion (and occasional disturbances) since the late 1960s have altered and enlarged the initial pattern is unknown. Soil sampling data have been taken over a number of years, but the data are insufficient to determine changes over time. Instead, the isopleth data were assumed to represent a static pattern for this scenario.

Compared to the rate of release calculated by Weber et al. (1998) for the high release days during the 1960s, annual release rates from vegetated, undisturbed surfaces are smaller by several orders of magnitude (based on calculations performed for Scenario 1). Similarly, neither the amount of actinide resuspended from the Site in a year, nor the amount that is redeposited on the Site in a year, exceed a few hundreds of a percent of the actinide already in the soil (again, based on Scenario 1). This supports an argument that the overall pattern may be fairly stable under undisturbed conditions, with the outer margins of contamination continuing to expand outward in ever decreasing amounts with time.

For the stable pattern scenario, the assumption was made that individual soil particles, with attached actinides, would move through the pattern represented by the isopleth data, but would not substantially alter it in the timeframe under consideration (hundreds of years, up to perhaps a thousand years). This scenario also assumed that the overall source area would continue to be covered by vegetation, and that the vegetative cover would remain largely undisturbed. Methods were devised (described below) to project the current pattern edges out to background (fallout) levels of Pu-239/240 and Am-241. Below background levels, RFETS-derived Pu-239/240 and Am-241 would be indistinguishable from plutonium and americium in the environment due to other sources and so were not considered in calculating the collective dose caused by Site emissions.

Moving Pattern Scenarios

The stable pattern scenario probably represents a realistic lower bound to the future

projection of collective dose. The assumption was made that, following Site closure, the public would be exposed to Site-derived airborne actinides at concentrations comparable to existing exposures, plus a small additional increment due to increased surface areas available for resuspension following closure. Minor amounts of actinide-contaminated soil may continue to move into the community at the pattern edges, but at levels virtually indistinguishable from background. The second scenario pursued a different possibility.

What if the pattern is not stable over the very long term? If substantial amounts of actinide-containing soil move beyond the Site boundaries, collective dose could be larger than that calculated for the stable pattern scenario because more people would be exposed to Site-derived airborne contamination. Unfortunately, there are few data available that would allow a realistic projection of how much, how fast, and how far contamination could spread. Instead, the second scenario concentrated on the ultimate endpoint of such a process. The scenario assumed that over some very long period of time, all of the actinide contamination in surface soils at the Site would move out into the community through resuspension and deposition. This would obviously represent an extreme upper bound to actinide migration through the air pathway.

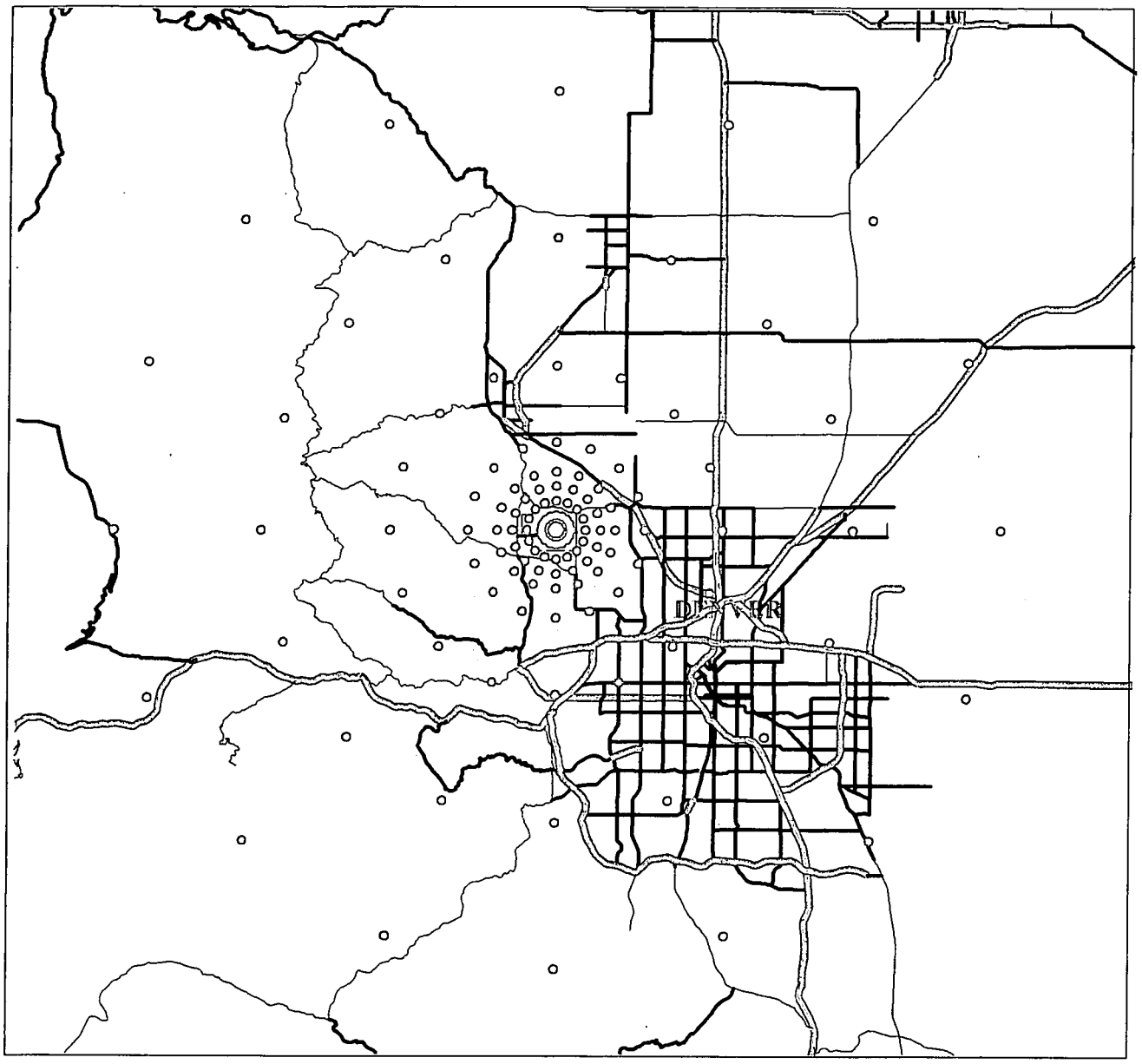
7.3.3 Emission Estimation and Modeling Methods

This section describes how future actinide concentrations were projected for each scenario. Both the stable and moving pattern scenarios assumed resuspension as the only emission mechanism, and further assumed undisturbed conditions—obvious simplifications, but a basis from which to proceed.

Base Case Scenario

Because of the uncertainties inherent in developing absolute estimates of future collective dose, the long-term chronic resuspension scenarios were treated as comparative studies. As a result, a "base case" was modeled representing existing collective dose and the other projections were compared to this.

The base case generally used the emission estimation and modeling techniques described for Scenario 1 (see Section 2.0). The sources modeled were also the same as those modeled for Scenario 1. However, calculation of collective dose required the estimation of concentrations over a much wider area than the receptor grid that was used for the Scenario 1 modeling. Consequently, a polar coordinate receptor grid was established covering the Denver metropolitan area to a distance of 56 km from the Site based on existing population information. The receptor grid is shown in Figure 7-4 and the population magnitudes associated with each portion of the receptor grid are shown in Figure 7-5. (Note: all the long-term scenarios calculated collective dose using the same receptor grid and population data so that the results can be compared.) Annual



Legend

○ Receptor

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10 0 10 20 30 Kilometers

NOTE:
Coordinates reference
UTM Meters, Zone 13, NAD27

Figure 7-4. Receptor Grid Used for Long-Term Modeling

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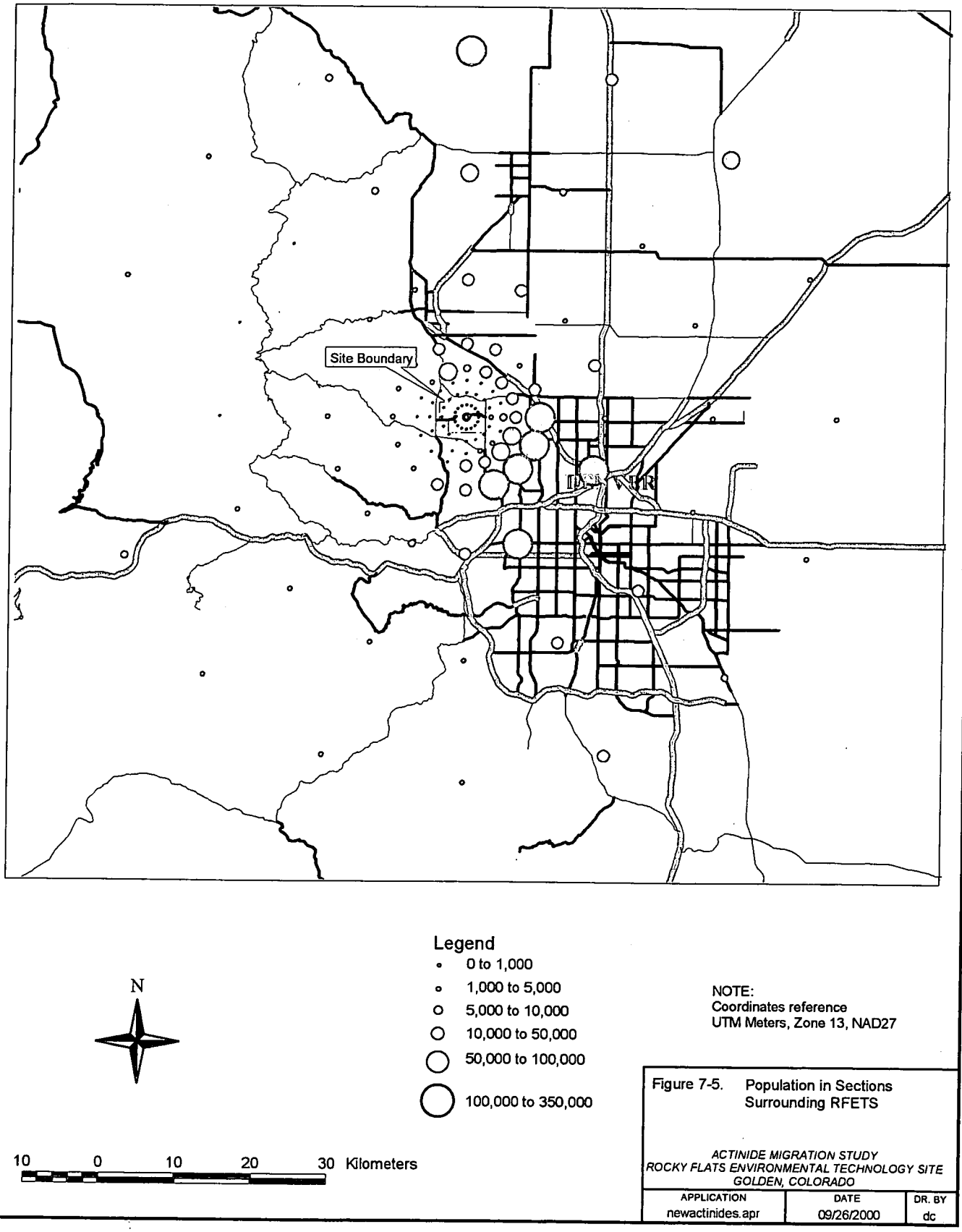

Figure 7-5. Population in Sections Surrounding RFETS

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Pu-239/240 and Am-241 concentrations were estimated using ISCST3 and the 1996 meteorological data set at the collective dose receptor locations.

Stable Pattern Scenario

To project actinide concentrations under the stable pattern scenario, a complete set of surface soil actinide isopleths out to background (fallout) levels was needed for both Pu-239/240 and Am-241. Background soil concentrations were considered to be 0.04 pCi/g for Pu-239/240 and 0.01 pCi/g for Am-241 (Chromec, 1999).

Surface soil actinide isopleths are well established for the Site proper. The information shown in Figures 2-3 and 2-4 was combined with soil data from the OU3 area (to the east of Indiana Street) to extend the isopleths to the east somewhat (RMRS, 1996). In many directions from the Site, especially for Pu-239/240, sampling data have been taken that extend the isopleths to background levels. In some directions, however, the isopleths based on sampling data do not extend to background level.

To fill in the gaps and extend the isopleths to background in all directions, for both actinides, the existing actinide concentration data for surface soils were graphed against distance from the 903 Pad in each of the 16 compass directions (shown in Figure 7-4). A set of power curves was found to fit the data well, with R^2 values ranging from 0.76 in the least prevalent wind directions to over 0.99 in the predominant wind direction. Concentrations were projected, as needed, to fill in the isopleths to background levels based on these power curves. The completed isopleths are shown in Figures 7-6 and 7-7.

The completed isopleths were used to establish area sources for modeling, using the same techniques that were described in Section 2.0. Resuspension emissions were calculated for the area sources using the Site-derived emission equation (see Section 2.2.1) and the 1996 meteorological data set, which was assumed to be representative of climatic conditions.

Annual concentrations, representing a projection to some distant time in the future, were calculated at each of the receptor locations shown in Figure 7-4 using ISCST3, using the methods that were described in Section 2.3.

Moving Pattern Scenarios

Two separate simulations were used to approximate collective dose calculations under the assumption that contaminated soils would migrate outward from the Site on a continuing basis. The purpose, as described previously, was to derive several potential upper bound estimates of future collective dose using different assumptions. The two scenarios that are described below represent situations that would expose greater numbers of people to airborne actinides compared with the stable pattern scenario assumptions.

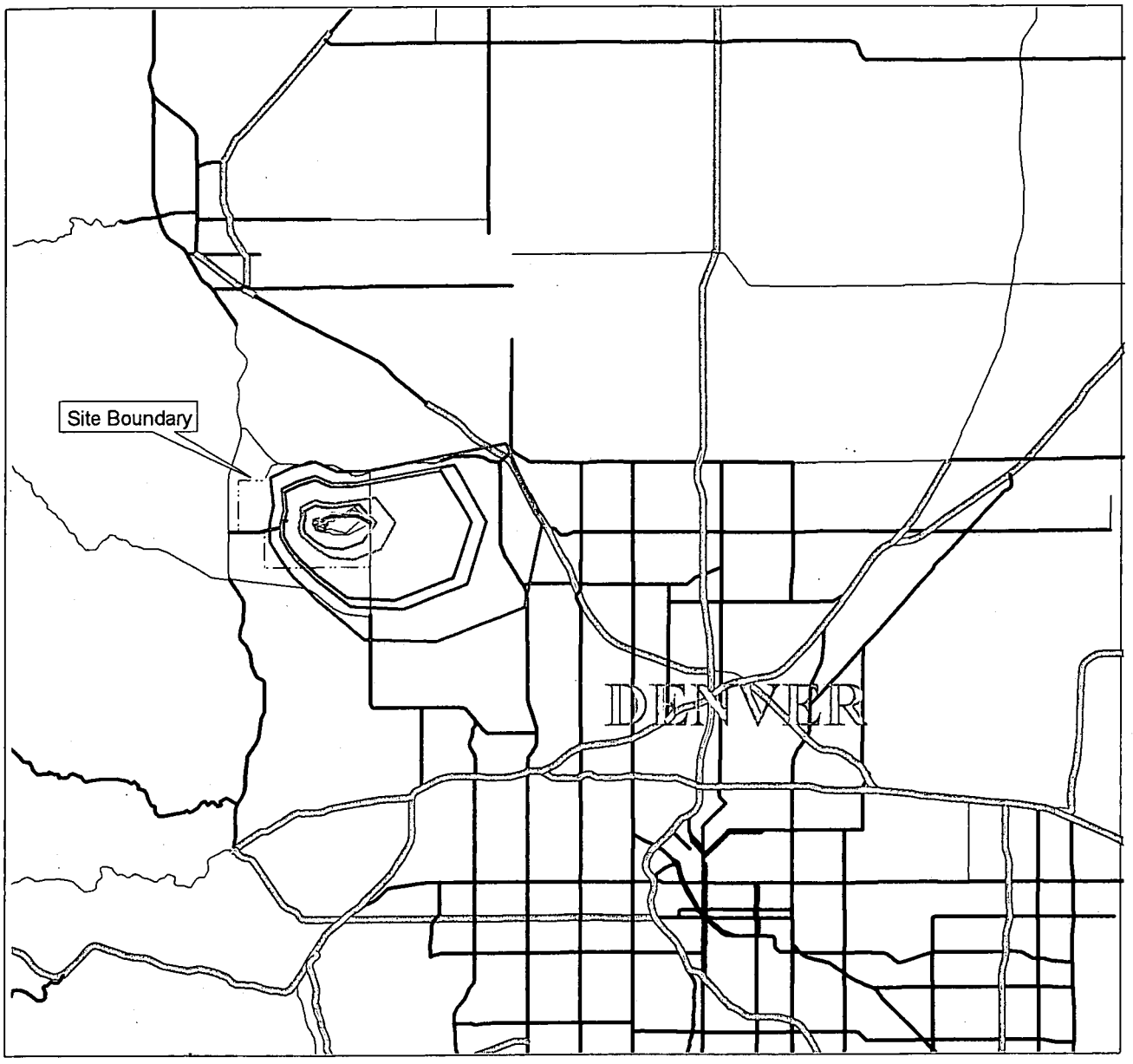

Figure 7-6. Stable Pattern Surface Soil Contamination Isopleths Used for Model Input for Pu-239/240

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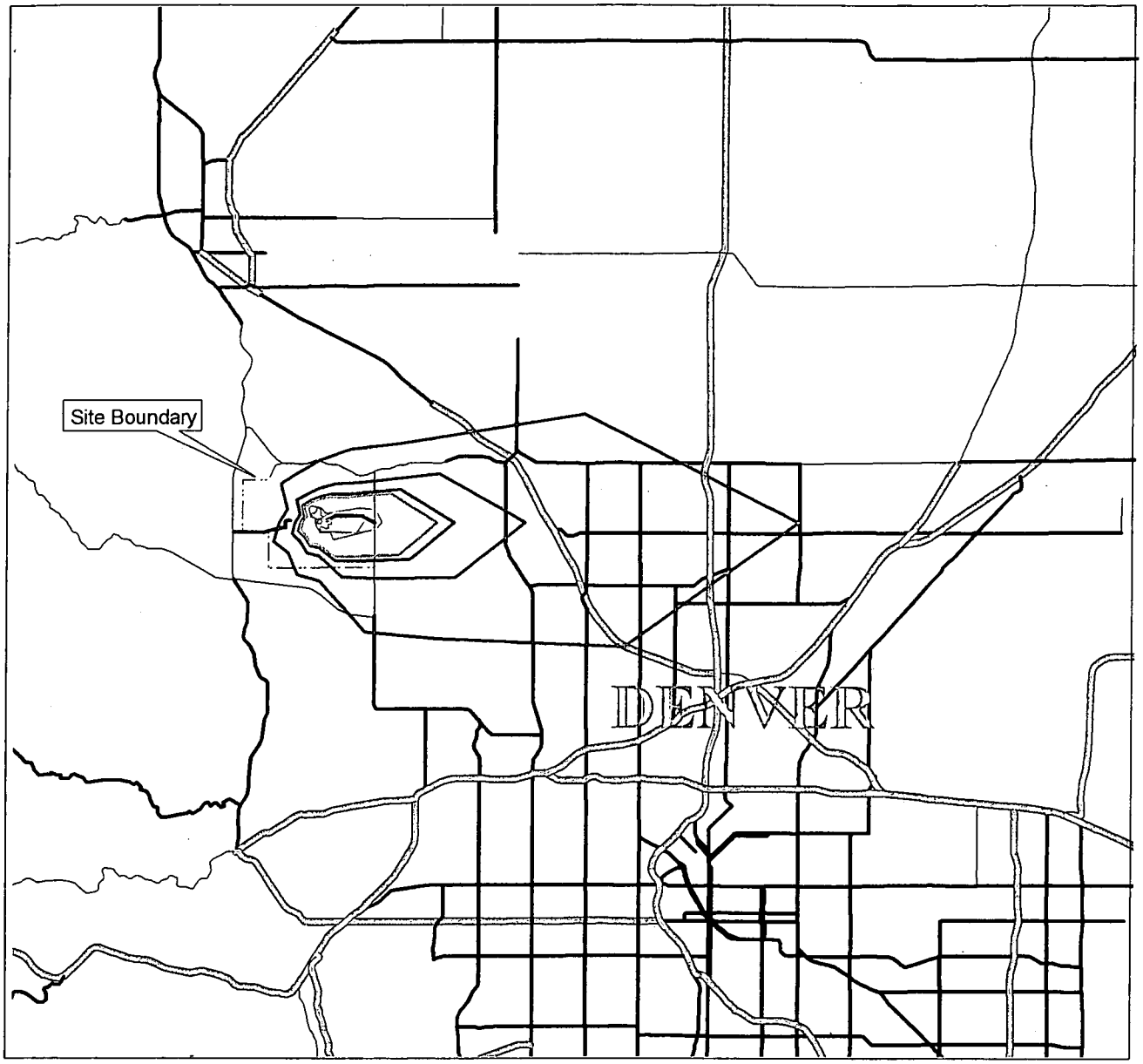

Activity Level for
Am-241 (pCi/g)

0.01
0.04
0.08
0.10
0.50

N

5 0 5 10 15 Kilometers

NOTE:
Coordinates reference
UTM Meters, Zone 13, NAD27

Figure 7-7. Stable Pattern Surface Soil Contamination Isopleths Used for Model Input for Am-241

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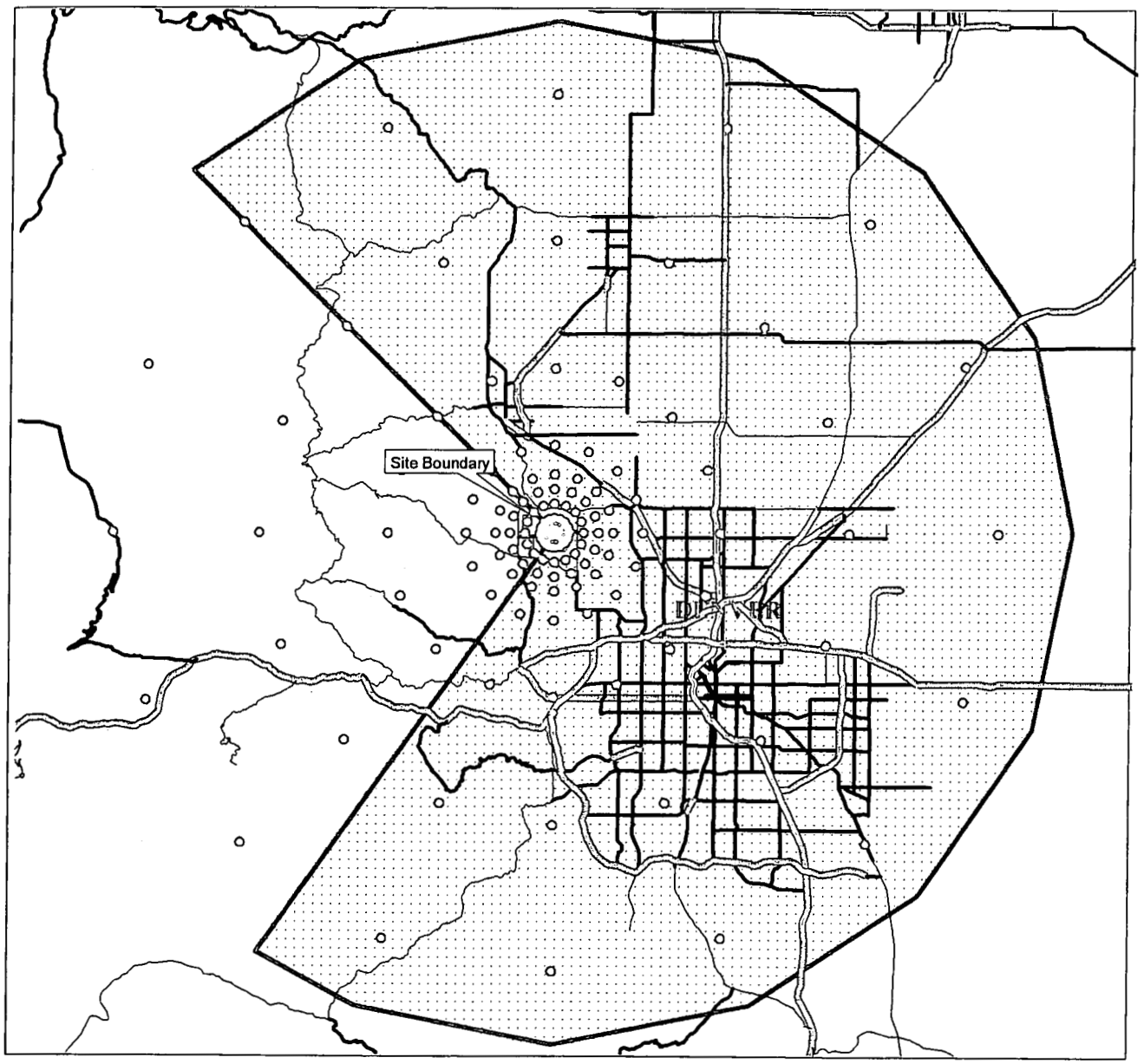
Complete Migration—The first scenario assumed that over some long period of time, the inventory of Pu-239/240 and Am-241 in Site soils would migrate from the Site through resuspension and be evenly redistributed in "downwind" soils. The maximum area over which redistribution would occur was assumed to be a portion of that covered by the polar receptor grid shown in Figure 7-4. Migration was assumed to occur toward the east, north, and south but not to the west, based on prevailing winds at the Site. The resulting redistribution area was represented by a 260° wedge, originating at the Site and extending from the Site to the limits of the polar receptor grid (56 km) in a generally easterly direction. The "complete migration" area is shown in Figure 7-8.

The inventory of Pu-239/240 and Am-241 in Site soils was calculated from the isopleth areas shown in Figures 2-3 and 2-4 (areas beyond the Site fenceline were not included but should represent a relatively modest addition to the total actinide inventory). Isopleth areas were converted to soil volumes using a 5-cm depth (the actinide concentrations associated with each isopleth are an average for the 0 to 5 cm layer of soil). Soil volume was converted to mass assuming an average bulk density of 1.2 g/cm^3 (Chromec, 2000). Total Pu-239/240 and Am-241 activities in Site soils were calculated by multiplying the soil mass associated with each isopleth (g) by the associated actinide concentrations (in pCi/g). The calculated actinide inventory was 4.2 Ci Pu-239/240 and 0.6 Ci Am-241.

The Site soil actinide inventory was evenly distributed over the area shown in Figure 7-8 (a total of 7,115 km^2). The Site-derived actinides were assumed to be mixed into the soil to a depth of 1 cm (over the long timeframe considered, some mixing will occur, although the depth of mixing will vary widely from location to location). The resulting calculated soil actinide loading was 0.05 pCi/g Pu-239/240 and 0.006 pCi/g Am-241. The entire redistribution area was used as a single large area source for which resuspension emissions were estimated using the Site-derived equation and an annual average wind speed of 4 m/s (based on 1996 meteorological data). The resulting emissions were modeled in ISCST3 using the receptor grid shown in Figure 7-4.

Limited Area Migration—The assumptions used in the previous scenario would have the effect of exposing a very large number of people to very small airborne concentrations of actinides. Because the collective dose is affected by both the number of people exposed and the estimated airborne exposure levels, a second scenario was developed using somewhat different assumptions. The effect of the revised assumptions would be to expose fewer people to somewhat higher airborne actinide concentrations.

The second scenario also started with the assumption that the entire actinide inventory in Site surface soils would migrate into the community over a long period of time, but assumed that the actinides would be redistributed over a smaller area than in the complete migration scenario. This "limited area migration" scenario would result in higher soil concentrations, with resulting higher resuspension fluxes.



Legend

Receptor

Source Area for Resuspension

NOTE:
Coordinates reference
UTM Meters, Zone 13, NAD27

N

10 0 10 20 30 Kilometers

Figure 7-8. Complete Migration Area Source for Long-Term Modeling of Am-241 and Pu-239/240

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To bound the area over which actinides would be redistributed, the population distribution shown in Figure 7-5 was examined. The major population areas to the east of the Site would be contained within an area centered at the Site and extending no more than 13 km to the east, north, and south. Using this limited area over which to assume redistribution of the actinides contained in Site soils would maximize population exposure. The resulting redistribution area would be 382 km^2.

To complete the emission estimation and modeling, a source area was developed over a 260° wedge originating at the Site and extending toward the east, north, and south to 13.0 km. The source area is shown in Figure 7-9. Resuspension emissions were estimated for this area using the Site-derived equation and an annual average wind speed of 4 m/s (based on 1996 meteorological data). The resulting emissions were modeled in ISCST3 using the receptor grid shown in Figure 7-4.

Other Considerations

An additional consideration for long-term dose is whether or not additional radioactive decay will substantially alter the isotopic activities on which the collective dose was based. Radioactive atoms are by definition unstable and spontaneously lose energy/mass through radioactive decay. With each such disintegration, an atom of one element becomes an atom of a different isotope or element. Different substances and isotopes will decay at different rates. The faster a substance decays, the higher its specific activity and the shorter the half-life, where the half-life is the expected time over which one-half of the remaining atoms in a population will decay.

Over a period of several half-lives, most of the original substance can be assumed to have decayed. For example, after seven half-lives, the remaining activity will be less than 1% of the original activity.

The Pu-239/240 and Am-241 in Site soils are generally derived from weapons grade plutonium that was used in weapons production activities, and associated chemical recovery and purification operations, at the Site. The weapons grade plutonium in Site soils was produced many years ago; certainly, any contamination derived from the 903 Pad must be well over 30 years old because the last drum was placed on the pad in January 1967 (ChemRisk, 1992).

Am-241 results from the decay of Pu-241, a minor component of the original weapons grade mix. The half-life for Pu-241 is 13.2 years, while Am-241's half-life is 458 years. Given the age of the Site weapons grade plutonium, most of the Pu-241 has already decayed to Am-241. Given the relatively long half-life of Am-241, the simplifying decision was made to treat it as stable over the timeframe of interest in the long-term scenarios (a few hundred to a thousand years).

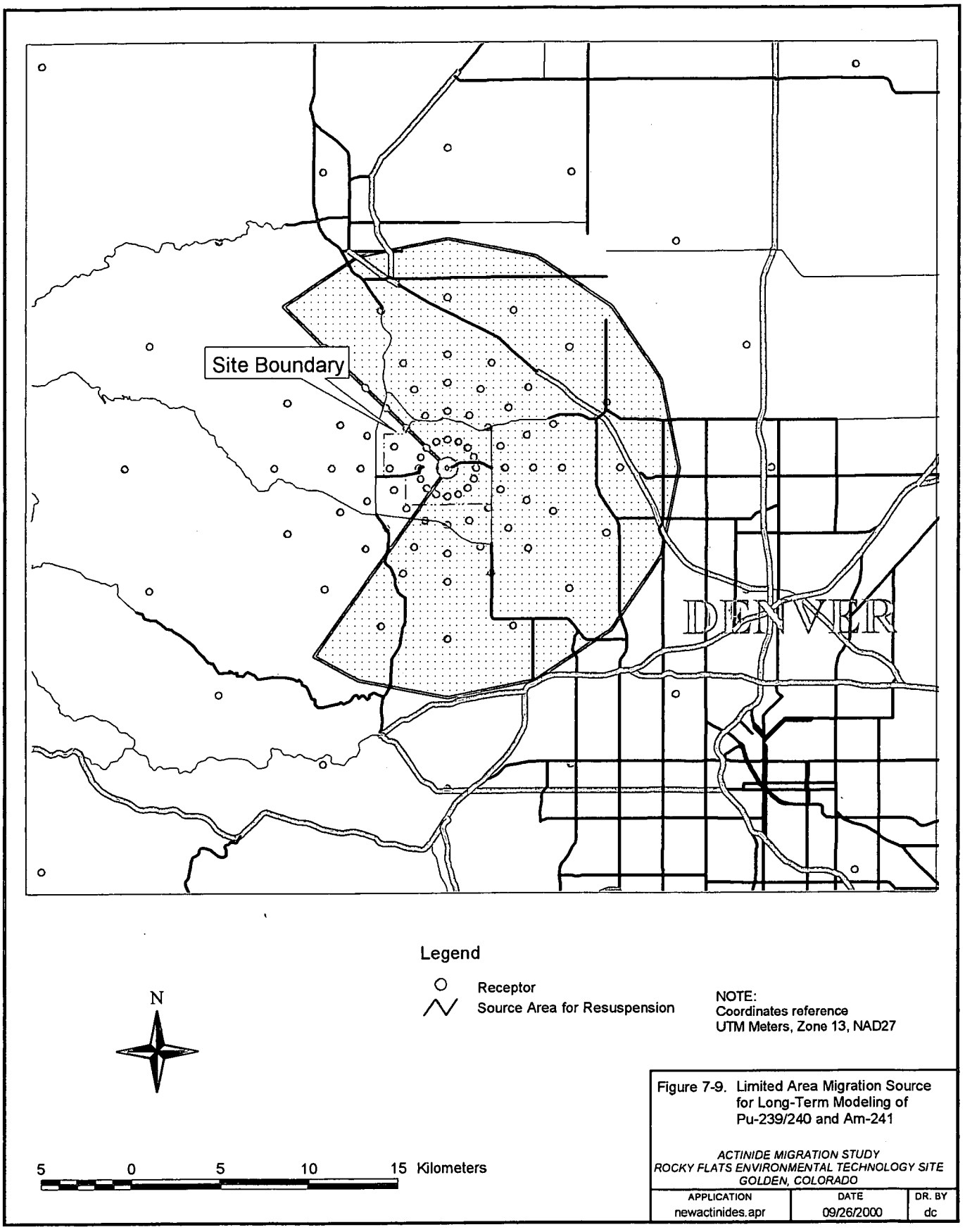

Figure 7-9. Limited Area Migration Source for Long-Term Modeling of Pu-239/240 and Am-241

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Pu-239 makes up the majority of the Site weapons grade plutonium (Pu-239 and Pu-240 are reported together because they cannot be distinguished from one another by typical analytical methods, but nearly all of the Site plutonium is Pu-239 rather than Pu-240). The half-life of Pu-239 is approximately 24,000 years. As a result, it was considered stable over the timeframe of the long-term scenarios.

The current isotopic activities are effectively constant for the long-term scenarios. Given the large uncertainties in the other assumptions made, this simplification should not greatly impact the estimated collective doses.

Collective Dose Calculation

As described above, airborne actinide concentrations were calculated at the receptor locations shown in Figure 7-4 for all the long-term scenarios. The concentrations were converted to a collective dose using conversion factors from the CAP88 model. CAP88 is a dose assessment model that was developed by EPA for use in determining compliance with federal regulatory limits for airborne radionuclide dose. The Site has historically used this model to determine compliance with 40 CFR 61, Subpart H, *National Emission Standard for Emissions of Radionuclides Other Than Radon from DOE Facilities*.

To calculate collective dose, the annual average airborne actinide concentration at each receptor location (pCi/m^3) was multiplied by the annual average breathing rate used in CAP88 (8,033 cubic meters of air per year [m^3/yr]), then multiplied by the actinide-specific conversion factor used by CAP88 to calculate inhalation dose. The resulting individual EDEs at each receptor location were multiplied by the population within the grid cell to calculate a collective dose over a specific grid cell. The collective doses for the individual grid cells were summed to determine a collective dose for the entire grid for each actinide.

Population Assumptions

Current population data were used to calculate collective dose for each scenario, since the long-term future population of the region is an unknown quantity. Future population growth will increase collective dose, even if no further migration of contaminants occurs, because collective dose is a function of population as well as airborne actinide concentrations.

7.3.4 Model Results

The collective dose comparisons for the various long-term scenarios are summarized in Figure 7-10. Each collective dose shown in Figure 7-10 represents a one-year scenario and is shown as the projected EDE normalized to existing conditions. In addition to the.

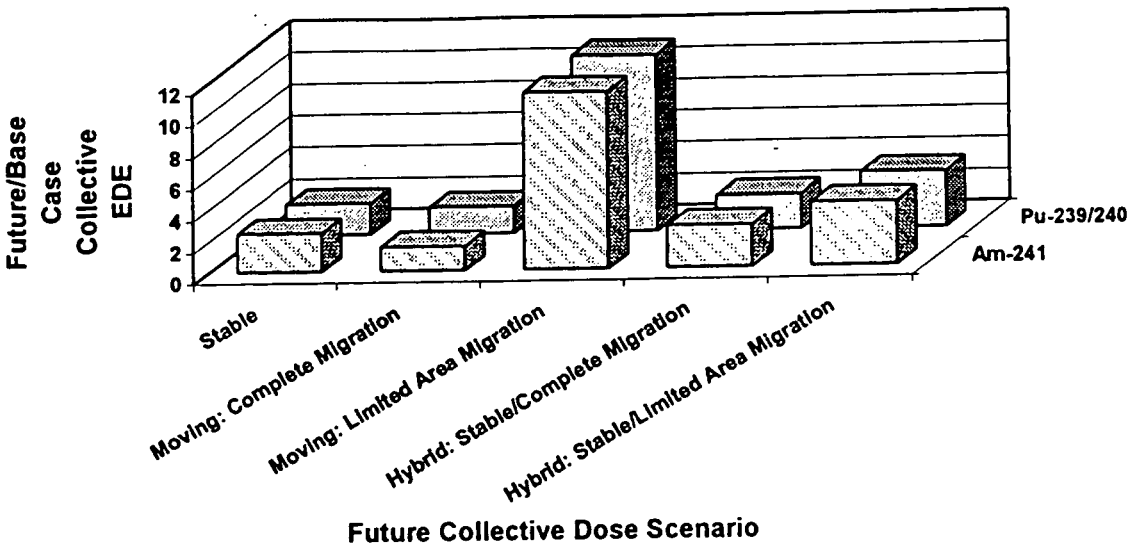

Figure 7-10. Annual Future Collective Dose Projections

collective dose projections discussed previously, two hybrid collective doses are also shown, as discussed below

7.3.5 Discussion

As shown in Figure 7-10, different assumptions regarding the extent of contaminant migration from the Site produced quite different projections of collective dose. The different projections are discussed below.

Stable Pattern Scenario

If the Site soils remain undisturbed, the stable pattern scenario may be a realistic projection and should represent a reasonable lower bound for future collective dose. Under this scenario, the collective dose was predicted to approximately double relative to the base case, although very little of the increase is expected to occur because of continued outward migration at the pattern boundaries, as explained below.

Much of the increase shown in Figure 7-10 for the stable pattern assumptions is due to the expected increase in surface area available for wind erosion following Site closure. Scenario 1 and Scenario 5 illustrate this difference for the MEI; the on-Site MEI dose was projected to approximately double (see Table 2-2 and Table 6-2). On average, the

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predicted increases in post-closure concentrations were somewhat less than the projected MEI increase—average concentrations along the eastern fenceline were predicted to increase by 30% to 50%, for example, following Site closure. In either case, the predicted increase was due to removal of pavement and buildings on Site, which will consequently create new areas subject to wind erosion, thereby increasing emissions due to wind erosion of Site soils.

Part of the increase in collective dose projected for the stable pattern scenario was also the result of including areas beyond the Site fenceline in the source areas that were modeled. The base case used isopleth data that generally stopped at the fenceline; the long-term projection, in contrast, included data on **existing** contamination to the east of the Site as well. This artifact of the different modeling assumptions made for Scenario 1 and for the long-term scenario accounted for an unknown amount of the predicted collective dose increase shown in Figure 7-10.

Additional **future** contamination predicted by projecting the contamination patterns out to background levels for each actinide is the third factor that increased the predicted dose. Only this third factor actually represents a collective dose increase due to outward migration of contaminants from the Site.

If contaminated soils on Site are repeatedly disturbed in future years, the pattern would be expected to change, with resulting changes in collective dose. Ongoing disturbance (for example, annual plowing) would probably result in more contamination moving further from the Site, over a shorter time period than would be expected under undisturbed conditions. This would increase collective dose by bringing the contamination closer to the higher population areas within the study area.

Moving Pattern Scenarios

The moving pattern scenarios projected collective doses that bracketed the doses for the stable pattern. To a large extent, the different predictions resulted from different assumptions about where the soil contamination will be in future years. In the case of the moving pattern scenarios, the contamination was assumed to be spread much more widely and uniformly across the community than the base case or stable pattern scenarios.

It should be noted that neither of the moving pattern scenarios represents a **realistic** projection of how contamination is expected to behave and move. The assumptions on which these scenarios were based were somewhat arbitrarily chosen to portray upper bound projections of collective dose. Also, unlike the stable pattern scenario, where soil disturbance would move more contamination into the community, the moving pattern scenarios represent different attempts at projecting the maximum extent to which soil contamination **could** be spread. These scenarios are useful for comparative purposes and

to suggest where future efforts should be concentrated if additional refinement of collective dose projections is warranted.

Hybrid Scenarios

Based on the information developed for the stable pattern and moving pattern scenarios, collective dose was also estimated from two "hybrid" scenarios. In this case, the majority of the Site surface soil actinide inventory was assumed to remain in place over the collective dose timeframe. As with the stable pattern, soil particles, with attached actinides, were assumed to move through the pattern without producing substantial changes in the pattern. The difference between the hybrid scenarios and the stable pattern scenario is that some additional migration was assumed to occur over large areas beyond the stable pattern's edges. This final scenario therefore combined the predictions for the stable pattern with an additional increment of dose based on the moving pattern results, but using more realistic projections of total contaminant migration.

Total contaminant migration over the timeframe of interest was calculated from the data developed for the FY00 air pathway modeling. Potential actinide resuspension from the Site (assuming no paved areas or buildings remain) was calculated over a 1-year timeframe from the existing isopleth data for Pu-239/240. The calculation indicated that a total of 0.001 Ci of Pu-239/240 could be resuspended each year (which is likely to be an overestimate, based on the comparison of modeled and measured concentrations that was discussed in Section 2.0). Deposition onto the Site was also calculated from the post-closure analyses (Scenario 5). A total of 0.00042 Ci Pu-239/240 was estimated to be redeposited back onto the Site each year. The predicted net annual loss was approximately 0.00058 Ci Pu-239/240. Assuming a total soil inventory of 4.2 Ci Pu-239/240, this annual loss rate would not deplete the existing surface soil inventory for over 7,200 years.

Over a 1,000 year timeframe, and assuming the same source configuration, the total loss from the Site would be 0.58 Ci Pu-239/240. Since the two moving pattern scenarios assumed that the entire 4.2 Ci soil inventory of Pu-239/240 would be spread evenly over various areas, the ratio between the calculated 1,000 year net loss and the total Pu-239/240 inventory can be used to ratio the modeling results. The resulting ratio (0.58/4.2 = 0.138) was applied to the estimated collective doses for the complete and limited area migration scenarios to calculate additional "increments" of collective dose that would result from continued migration beyond the stable pattern edges. The same ratio was used for both Pu-239/240 and Am-241 and the collective dose increment was added to the stable pattern results to yield the hybrid scenario projections shown in Figure 7-10. The hybrid scenarios represent more realistic projections of actinide migration than either of the moving pattern scenarios.

7.4 Conclusions

Three issues were explored in this section. In Section 7.1, it was shown that high winds would increase airborne actinide concentrations due to resuspension, even though dispersion would be improved under these conditions.

Section 7.2 explored the effect that periodic disturbances would have on post-closure impacts. Disturbances would increase airborne actinides in proportion to the area disturbed, the frequency of disturbance, and the contaminant concentrations in the disturbed area. In addition, high winds shortly after disturbances would be particularly effective in resuspending soil and associated actinides.

Section 7.3 explored several methods for predicting collective dose at some period in the future. A lower bound scenario suggested that collective dose would not increase substantially due to outward migration of actinides from the Site over long periods of time. The largest portion of the predicted increase over current conditions would instead occur due to post-closure increases in the surface area available for wind erosion, rather than continued outward migration of actinides. This factor was discussed in more detail in Section 6.0.

In contrast, other assumptions projected larger increases in future collective dose. The most realistic upper bound projections suggested that future collective dose might be 10% to 80% higher than the lower bound projections.

The collective dose investigation indicated that if refinement of the future collective dose is warranted, better data are needed regarding changes in surface soil contamination levels with time. A key assumption in projecting future collective dose is whether or to what extent the existing surface soil contamination patterns (and the actinide inventory contained in those soils) will change and spread over time. The rate of change or outward migration is also important.

This is a different question than predicting the migration of airborne actinides from the Site in any given year. The FY99 and FY00 air pathway studies have explored that question. What is not known is whether continuing movements of soil and actinides will serve to reinforce the existing contamination patterns over time or will actually change those patterns in a significant way, particularly at the current pattern edges. The interaction of wind erosion and other actinide migration pathways is also important in determining what levels of airborne actinides people in the metropolitan area will be exposed to in future years. These factors will be explored in FY01 by the actinide migration studies team as the information developed for the various migration pathways is correlated and summarized.

8.0 FY00 Air Pathway Findings and Recommendations

This section summarizes the findings of the FY00 air pathway work and presents recommendations and options for future work.

Air Pathway Findings

The FY00 work was designed to investigate emission scenarios and events that may be of interest with regard to actinide migration during and after Site closure. In general, the modeling estimated reasonable upper bounds for the expected impacts of closure activities and post-closure Site configurations. The results and conclusions from the FY00 modeling are summarized below.

- Modeling of chronic, natural resuspension under current Site conditions showed maximum concentrations and deposition of actinides to the east of the primary source areas on Site. The specific locations varied by actinide and reflect the differing distributions of various isotopes in Site soils, coupled with the prevailing direction of higher speed winds at the Site.

  A comparison of modeled estimates to measured actinide concentrations showed that the model underestimated measured actinide concentrations at samplers in the nondominant wind directions, while overestimating concentrations to the east and southeast of the source areas. The model performance at the locations where concentrations appeared to be underpredicted was generally within the accuracy of the measurements themselves. Model overpredictions in the direction of the stronger winds at the Site are probably at least partly due to inaccuracies in the emission estimation method. Even so, the model overpredictions were reduced from the FY99 modeling and are now within an order of magnitude of the measured concentrations.

- The results of the remediation scenario modeling indicated that annual average PM_{10} and actinide concentrations would be well within applicable standards for a remediation project conducted according to the assumptions made here. Use of additional fugitive dust control measures, such as a weather enclosure, would further lessen ambient concentrations of both particulate matter and actinides. Deposition of actinides to ground or surface water would also be reduced.

  Conversely, excavation of larger amounts of contaminated soil would increase airborne actinides and actinide deposition. Cleanup to more restrictive levels, such as removal of all soils contaminated at or above Tier II levels, for example, would result in excavation of additional soil, thereby increasing airborne actinide concentrations and deposition.

A high wind event during remediation would result in lower maximum impacts than normal remediation activities. Emission sources such as excavation and traffic would not emit during high winds. In addition, dispersion is increased during high winds. These factors more than compensate for the increase in emissions that would occur during a high wind event from bare ground surfaces and stockpiles.

- The D&D modeling analysis indicated that release of a highly contaminated pocket of concrete during demolition could result in relatively high but short-lived airborne actinide concentrations. The maximum impacts would occur very close to the release point. Concentrations at the facility fenceline would be several orders of magnitude less.

- Results from a simulated wildfire in the vicinity of the 903 Pad showed high particulate matter concentrations within the plume, but for a relatively short period of time. Maximum PM_{10} and actinide concentrations would occur under low wind speed, stable conditions, which would inhibit plume dispersion.

  A worst-case post-closure fire would produce slightly higher particulate and actinide concentrations than a similar pre-closure fire. The 903 Pad is not currently a source of fuel or actinide emissions because it is paved. Cleanup would lower soil actinide levels but would also expose the soil under the pad. The area was assumed to revegetate; therefore, the 903 Pad area would represent an additional fuel and actinide source for the post-closure fire, which would increase impacts.

  The post-fire resuspension scenarios showed that over the course of a year, a reasonable worst-case vegetation recovery scenario would result in a five-fold increase in actinide concentrations when compared to unburned conditions. The speed with which vegetative recovery would occur can affect the concentrations and resulting EDE substantially—the faster the recovery, the smaller the resulting increase in pollutant concentrations and EDE.

- Post-closure impacts due to chronic resuspension may be slightly higher than pre-closure impacts. Remediation projects will decrease actinide concentrations in Site soils, thereby decreasing the total actinides in the Site environment. However, removal of buildings and pavement will increase the soil surface areas available for wind erosion. Although only small amounts of actinides will be left in Site surface soils, particles and actinides will be resuspended from a significantly larger source area, with resulting increases in impacts to air from this small emission source. The maximum concentrations predicted would still be substantially less than the EPA air dose limit (10 mrem) and represent less than

2% of the average annual radiation dose received by residents of the Denver area from all sources.

- Investigations of various issues related to post-closure impacts showed that high winds can resuspend much larger amounts of particulate matter and actinides than lower wind speeds, with resulting increases in downwind concentrations. The effect of increasing wind speed on emissions is particularly pronounced if the ground surface has been disturbed by traffic, excavation, or any other natural or man-induced activity that renews the erodible surface layer of soil. The reservoir of resuspendable material is generally finite for most disturbance scenarios.

- Periodic disturbances would increase airborne actinides in proportion to the area disturbed, the frequency of disturbance, and the contaminant concentrations in the disturbed area. In addition, high winds shortly after disturbances would be particularly effective in resuspending soil and associated actinides.

- Several methods were explored for predicting collective dose at some period in the distant future. Over a very long time, actinide migration from the Site through the air pathway may increase public exposure and dose. While scenarios can be envisioned that would increase public exposure substantially, more realistic projections show an increase of between a few percent to less than a factor of four should Site soils remain undisturbed. This projected increase applies to the collective dose to the surrounding population; individual dose is not expected to increase over the long term. Additional population growth in the immediate Site vicinity would also be expected to increase collective exposure and dose.

Recommendations and Options for Future Work

The air pathway has not proven to be a threat to public health over the past decade, and emissions from vegetated areas with surface soil contamination do not seem to be of concern based on the FY99 and FY00 air pathway investigations. Understanding and demonstrating the mechanisms for resuspension are necessary to eliminate this natural pathway from consideration in future cleanup decisions, or to identify circumstances where the pathway may become important.

The FY00 air pathway work has provided information on the relative importance of a number of activities and situations that can influence actinide migration through the air pathway. This section describes areas where gaps in data or understanding are most pronounced and discusses both planned investigations and possible areas where future data gathering or additional modeling could refine model estimates.

The model developed in the FY99 work and refined in FY00 will be used along with other models for air regulatory compliance planning associated with proposed cleanup

alternatives at the Site. It is expected that additional modeling will be performed using the techniques outlined here as remediation or D&D projects at the Site proceed into the detailed planning phase and specific decisions are made regarding alternative strategies. While the air dispersion and emission estimation techniques used in the FY00 work represent a significant improvement over the FY99 tools, the techniques would benefit from additional data in some areas. Studies and data collection that would improve the accuracy and precision of model estimates are listed below.

- Wind tunnel data are being collected in FY00 that will help refine the emission estimation equation. Wind tunnel measurements were performed in Spring 2000 to measure resuspension of soil and ash immediately following a prescribed burn and at intervals after the burn to determine how the resuspension rates varied from those measured over unburned, undisturbed areas of the Site. Because of a small grass fire at the Site in July 2000, additional wind tunnel investigations were implemented. The grass fire burned an area with low levels of actinide contamination (approximately 2 pCi/g). The additional wind tunnel study gathered data on particle and actinide activity in different size fractions of resuspended material and in the underlying soil from the July wildfire area.

  Kaiser-Hill has contracted with MRI to perform the wind tunnel studies, using the same wind tunnel configuration that formed the basis for the chronic, natural resuspension emission factor developed in the FY99 air pathway work. Consequently, the FY00 wind tunnel measurements should provide additional data with which to refine the emission estimation technique, as well as provide new information regarding post-fire recovery. Wind tunnel data will be available in Fall 2000 and will be used to refine model estimates in FY01.

- One of the assumptions made in the FY99 air pathway investigation was that paved and unpaved roadways on Site were not sources of resuspendable actinides. This assumption was questioned by reviewers because no measurement data were available to confirm the assumption. If the roads in the vicinity of the 903 Pad contain measurable amounts of actinides in surface dust, the omission of this source from the modeling could lead to inaccurate results. As a result, direct measurement of actinide concentrations in road dust collected in the vicinity of the 903 Pad is planned for FY01. The results may be used to revise the air pathway modeling if the FY00 results and the results of the dust measurement program suggest that further modeling is warranted.

- If air pathway estimates prove to be of concern, data collection regarding dilution may also be useful. Dust within the vegetation canopy may consist partly of the ambient, underlying soil and partly of dust advected into the contaminated areas and then deposited. Over time, at any given point, only a portion of the total atmospheric loading of particulate matter will originate from Site sources. That

fraction of suspended particulates that is in turn deposited to the ground, water, or vegetation surfaces will therefore have actinide concentrations that represent a weighted average of contributions from surrounding clean and contaminated areas.

The modeling used a simplified assumption in FY99 and again in FY00 that the dust that was resuspended from contaminated areas of the Site contained actinides in the same concentration as the underlying soil (i.e., that there was no dilution). Although it is likely that dilution occurs, the data available at this time are insufficient to quantify it. A data collection program could be planned that would allow direct measurement of this factor.

- The collective dose investigation indicated that if refinement of the future collective dose estimate is desired, better data are needed regarding changes in surface soil contamination levels with time. A key assumption in projecting future collective dose is whether or to what extent the existing surface soil contamination patterns (and the actinide inventory contained in those soils) will change and spread over time. The rate of change or spread at the pattern edges is particularly important. This may also prove to be a useful area to investigate further.

- Additional modeling is recommended following receipt of wind tunnel and road dust sampling data. The data developed through these planned investigations can be used to further refine chronic resuspension, post-fire recovery, and remediation scenario analyses. The resulting resuspension information can also be used to refine long-term resuspension impacts.

9.0 References Cited

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Appendix A

Response to Comments on *Air Transport and Deposition of Actinides at the Rocky Flats Environmental Technology Site, FY99 Report* (Radian, 1999)

APPENDIX A

RESPONSE TO COMMENTS ON *AIR TRANSPORT AND DEPOSITION OF ACTINIDES AT THE ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE, FY99 REPORT* (RADIAN, 1999)

Reviewer #1

Comment: Methods. Despite assuming that resuspension from the soil surface by wind and rainsplash to vegetation surfaces was negligible (due to heavy vegetation cover), they went ahead and used releases at the soil surface as the source of emissions. They assumed that the dust particle sizes on the vegetation were present in the same proportion as that occurring on the soil surface.

Response: The wind tunnel data that were used to generate a chronic resuspension emission estimation technique for the Site were taken over vegetated surfaces that appear representative of areas of surface soil contamination at the Site. Therefore, the specific source of emissions was not determined—whether the emissions came primarily from the soil surface, from litter, or from dust blown off vegetation. However, the data should provide an appropriate basis for modeling of resuspension from Site surfaces in the absence of disturbance or excessive winds.

With respect to the particle size distribution, the data used in the model are based on air sampling to the east of the 903 Pad, at a 1-meter (m) height. These data were used for the mass and activity fractions, rather than surface soil data, because what becomes airborne may not precisely match the mass and activity fractions in the surface soil itself. For example, in some size fractions, both primary mineral soil particles and aggregates may be found. It is possible that aggregates are preferentially resuspended, rather than mineral soil, because the particles are less dense.

Comment: General Comments. More discussion is needed on the potential use of the results, such as how it would be integrated and implemented into some 'master model' of the RFETS. Some discussion is needed on just how the modeling technology would be used to demonstrate compliance or to make cleanup decisions.

Response: The air pathway has not proven to be a threat to public health over the past decade, and the emissions from vegetated surface contamination do not seem to be of great concern. Understanding and demonstrating the mechanisms for resuspension are necessary to eliminate this natural pathway from consideration in future cleanup decisions, or to identify circumstances where the pathway may become important.

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Information about the air pathway and "what-if" scenarios will be integrated with information developed about other pathways of actinide migration in the Pathway Analysis Report that will be developed in fiscal year 2000 and 2001 (FY00/FY01). In addition, all the information developed through the actinide migration evaluation project will ultimately feed into a number documents that implement Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) requirements.

In addition to direct uses in the actinide migration study, the model will form the basis for air quality planning associated with proposed cleanup alternatives at the Site. The model can be used to show comparative impact levels for various scenarios and control techniques. The FY00 report will more fully explore these uses.

Comment: Background, p. 1-1. The basic assumption in this report is that the 903 Pad is the primary source area for actinides. I have seen no data to confirm that the 903 Pad area is contributing the actinides measured in air at the perimeter locations. For example, I would like to see data that shows that the industrial area is NOT a major source of actinides for transport to downwind areas.

Response: Sources of actinide emissions at the Site include stack emissions, resuspension of contaminated soils, and a variety of projects that disturb contaminated soil or handle other contaminated materials. Stack emissions are a small factor because most are vented through high efficiency particulate air (HEPA) filters, which results in very low emissions. Stack emissions typically account for 1% or less of the annual airborne dose from the Site, as modeled using the CAP88 dispersion/dose model.

Resuspension of contaminated soil occurs mainly outside of the Industrial Area because of the large amount of surface area covered with buildings, roads, and parking lots. Excavation and especially traffic associated with projects in areas with soil contamination result in emissions. Observations of airborne actinides at sampling locations in and around the Industrial Area show considerably lower concentrations at all other locations compared to those to the east of the 903 Pad, with rare exceptions. As a further comment, the nearest sampling location to the west-northwest of the 903 Pad lip area shows significantly lower actinide concentrations in the air than samplers immediately to the east and southeast of the lip area (i.e., samplers in the prevailing downwind direction). This appears to substantiate the major source contribution from the 903 Pad.

Project emissions (only some of which originate within the Industrial Area) vary from year to year and depend on the type of activity and the actinide content of the soil or other materials handled. Some years they are indeed the major source of airborne dose at the Site. For example, in 1996, radionuclide emissions from

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two specific projects contributed over 90% of the annual airborne dose from the Site, while in other years, resuspension has been the major source.

The Site prepares a detailed inventory of all sources of radionuclide emissions to air each year, as required by Title 40 of the Code of Federal Regulations (CFR), Part 61, Subpart H, *National Emission Standards for the Emission of Radionuclides Other Than Radon from Department of Energy Facilities.* Based on these reports, the 903 Pad area and the surrounding areas have been the major source of actinide emissions in recent years when project emissions are low.

The Site routinely analyzes filters from sampler S-107, located just to the east of the 903 Pad, as well as several samplers at the Site perimeter (3 samplers in 1996, up to 14 samplers currently). For 1996, the plutonium 239/240 (Pu-239/240) concentrations measured at S-107 and at two perimeter samplers are shown in Tables 4-1 and 4-2 from the FY99 air pathway report. Note that the Pu-239/240 concentrations at S-107 are consistently two orders of magnitude higher than what is seen at the fenceline, indicating that some of the actinide emissions are from the local, 903 Pad area. Similar samplers inside the Industrial Area that have been analyzed in recent years show Pu-239/240 concentrations that are consistently lower than those at S-107 but higher than the perimeter samplers, indicating that the Industrial Area is a secondary source of plutonium emissions.

It is important to note that what was modeled and reported in FY99 was resuspension from Site soil and vegetation surfaces (natural, chronic resuspension in the absence of anthropogenic disturbance). Actinide emissions from this source type were based on isopleths of surface soil contamination for the entire Site. Even though the 903 Pad area shows higher levels of surface soil contamination for plutonium and americium (Am) than other portions of the Site, nothing was eliminated from the database for the modeling runs. Also, the main source areas for uranium contamination are not near the 903 Pad but encompass different portions of the Site. Isopleth maps for all isotopes modeled will be presented in the FY00 report.

The comparison of model results to measured plutonium levels that was discussed in the FY99 report contains the inherent assumption that natural resuspension was the only significant source of plutonium emissions during 1996. As discussed above, this was not the case; however, for a number of reasons, other sources and events probably did not greatly influence annual measured plutonium levels at the samplers used for the comparison, as explained below:

- For samplers S-007 and S-107, the 903 Pad is almost certainly responsible for the vast majority of Pu-239/240 measured because these samplers are

located just east of the 903 Pad area in the predominant downwind direction.

- For the perimeter samplers (S-138, S-038, and S-207), other source areas must be considered. However, based on an analysis of emission data for the Site for 1996 and associated meteorological data, it is expected that soil contamination was a major source of measured Pu-239/240 at these samplers as well.

  In 1996, two project-related emission events produced the largest fenceline dose, rather than resuspension from surface contamination. Both projects (the Trench-3/Trench-4 [T-3/T-4] excavation and draining of the 774 clarifier tank) occurred over relatively short time periods when the prevailing winds were to the north and east, rather than toward samplers S-138, S-038, and S-207. In addition, the release from T-3/T-4 was largely uranium, rather than plutonium. As a result, annual Pu-239/240 concentrations at S-138, S-038, and S-207 were likely dominated by resuspended surface soil contamination.

Comment: Page 2-3. Resuspension of Radioactive Material. The statement that resuspension factors for the 903 Field sampler ranged from 10^{-13} to 10^{-10} should be explained in more detail, since it contrasts with the authors' statement that: "This observation is noted as confirming the time-dependency of contaminant resuspension, which predict an approximately constant resuspension factor, once weathering of the deposit has occurred."

Response: The notation regarding resuspension factor ranges from the 903 Field sampler was meant as a contrast to the resuspension factor of 10^{-9} m^{-1} calculated for areas contaminated by the Chernobyl incident and was not meant to reflect changes in resuspension over time at the Site.

Comment: Pages 2-5 and 2-6. The statement is made that the larger particles are aggregates. A reference is needed to support this statement. Also, the particle density of 2.5 g/cm^3 is what you would expect for a primary particle, not an aggregate.

Response: We've refined the assumptions regarding particle size, composition, and density for the FY00 modeling. As the reviewer notes, aggregates would be less dense than pure mineral soil. Based on a theoretical breakdown of size fractions and densities for generic soil given in Foster, G.R., G.C. White, T.E. Hakonson, and M. Driecer, 1985. *A Model for Splash and Retention of Sediment and Soil-Borne Contaminants on Plants.* Transactions of the ASAE, 28(5), p. 1512, the size fractions will be modeled as follows:

- <3 micrometers (μm) diameter, 2.65 grams per cubic centimeter (g/cm^3) (assumed primary clay particles);

- 3-15 μm, 2.65 g/cm^3 (assumed primary silt particles); and
- >15 μm, 1.8 g/cm^3 (assumed small aggregates).

This breakdown is consistent with soil specific gravity data taken in the Woman Creek drainage and near the South Interceptor Ditch on Site.

Comment: Page 2-5. The statement is made that "most of the airborne Pu is carried on larger particles". Depending on how the authors define "larger particles", this statement is not necessarily true. What is meant, I think, is that 70% of the total Pu inventory in dust is associated with coarse particles because coarse particles make up most (i.e., 60%) of the total dust mass.

Response: The reviewer's interpretation is correct; 70% of the total plutonium inventory in airborne particulate is associated with the largest of the three size fractions considered (>15 μm), which also represents the largest mass fraction. Terms like larger and smaller are confusing when discussing soil particles and airborne dust because they have different meaning for different readers. In the case of the FY99 report, the size fractions discussed relate specifically to Langer's multi-year airborne particulate studies carried out to the east of the 903 Pad. The size fractions from those studies were used for the Industrial Source Complex Short-Term (ISCST3) modeling and represent particles with aerodynamic diameters <3 μm, between 3 and 15 μm, and >15 μm.

Comment: Page 2-7, 1st and 2nd paragraphs. The discussion about the lack of saltation from the bare soil areas leads me to wonder just how the vegetation gets contaminated. If dust blowing off of vegetation is the major source of actinides for downwind transport, then saltation and resuspension from bare soil surfaces must occur I think. If not, then what is the source of dust and actinides on vegetation? Also, the dismissal of roads as a source term in the study is not valid in my opinion. I believe they may be a major source of dust and possibly actinides.

Response: There are many sources of dust in the air that, through deposition, would result in dust on vegetation surfaces. Fewer sources would result in actinide contamination, however. These may include some saltation from bare soil areas during high winds, as well as rainsplash and attachment of soil to growing vegetation surfaces. In addition, stack emissions and on-Site excavation involving contaminated soils are also sources, although stack emissions are very low due to HEPA filtration.

The reviewer also makes a good point regarding roads—traffic is the largest source of particulate emissions on Site and any actinides on unpaved or paved road surfaces could add to the loading on vegetation and in the air downwind. Even small amounts of surface contamination on roads would be subject to frequent resuspension by traffic or wind, since disturbance by traffic serves to

renew the erodable surface layer on unpaved roads. Consequently, the assumption that road surfaces are uncontaminated will be reevaluated under specific scenarios that will be modeled in FY00.

Comment: Page 2-7, 3rd paragraph. I am not sure what the authors mean by "on a mass basis"—is it mass of soil or mass of vegetation? Concentrations of actinides in vegetation should be less than that in soil since activity in vegetation is normalized to vegetation mass while activity in soil is normalized to soil mass. If instead they mean the soil mass attached to the vegetation, then I am not sure that I believe what the authors imply—that advection dilutes actinide concentrations in soil attached to vegetation surfaces. I doubt that Langer was able to separate soil from organic debris when he washed off plant surfaces to remove attached soil. Therefore, his measured actinide concentrations may be diluted with plant debris. Little and Arthur's work do not, I think, say what the authors imply—their work is based on a plant to soil concentration ratio.

Response: We were referring to the concentration of actinides normalized to the mass of the soil attached to the plant—not to the vegetation mass. Langer washed soil off a plant surface and compared the resulting concentration (picocuries plutonium per gram of soil [pCi/g]) in the soil sample obtained with the actinide concentration in the underlying soil. The sample from the plant surface had approximately 1/5th the actinide concentration of the underlying soil although, as the reviewer points out, some plant debris was probably also dislodged by the washing procedure. Langer also measured concentrations in ashed samples of unwashed vegetation and vegetation + litter, and found that the actinide concentrations decreased from the soil to the vegetation + litter to the upper vegetation surfaces.

Many researchers have looked at the concentration of actinides on/in vegetation normalized to the vegetation mass. Unfortunately, the only research we have been able to find in the literature that looked specifically at concentrations in soil attached to the external surfaces of plants compared to the soil beneath the plants was Langer's one experiment.

The work of Little and Arthur and other researchers cited only supports the dilution effect shown in Langer's experiment indirectly because none of them measured this directly. However, a number of researchers at Rocky Flats have looked at concentration ratios (actinide concentration normalized to vegetation dry weight) and others have looked at soil attachment on a mass basis. Combining this information and assuming that most of the actinide (generally plutonium has been looked at in the most detail) is found in soil attached to plant surfaces rather than internal to the plant, a rough approximation of actinide concentration on vegetation can be obtained relative to underlying soils. As noted in the FY99 report, this type of calculation generally supports dilution.

Comment: Page 2-7, 4th paragraph. I have seen nothing so far presented by the authors that convinces me that dilution due to advection and deposition of clean particles is important as a source of soil on vegetation surfaces or even whether it occurs. The authors go on to say that particle size discrimination during transport of soil to vegetation surfaces would cause further dilution. In fact the opposite is true in that the particles that get transferred and retained by vegetation are the smaller size fractions that almost always contain the highest concentrations of actinides.

Response: Advection seems to be a plausible source of continuing dust deposition on vegetative surfaces, which would result in the dilution effect noted. The ultimate source is not necessarily a "nearby" contaminated soil surface; instead, there are many other local and regional sources that contribute particulate matter to the air over the Site. Most of these will be sources of "clean" particulate matter with much lower actinide content than the underlying soil in the contaminated areas.

At the Site itself, particulate matter sources (other than wind resuspension) include combustion sources such as the Steam Plant and diesel generators/compressors, miscellaneous projects that require soil excavation ranging from steam line replacement to remediation activities, stack emissions, and traffic. Of these sources, many emit relatively "clean" (nonradioactive) particulate matter. Of the particulate sources listed, traffic (paved and unpaved road emissions plus tailpipe emissions) is the largest source.

Regionally, particulate sources include fugitive dust, traffic, and industrial emissions. Industrial sources are small compared to traffic. Fugitive dust sources are probably important locally in the area around the Site—there are several large sources of "clean" particulate near the Site fenceline. These include a large sand and gravel operation located at the West Gate, a quarry and kiln along the northwest fenceline, and a number of nearby development projects that have moved a lot of dirt in recent years. These include reservoir improvement projects on south Indiana, water tank construction on the corner of Indiana and Highway 128, the Broomfield jail work, Interlocken construction, etc. over the past three to four years.

The net effect is that there is a lot of particulate matter in the air over the Site at any given time, only a small part of which can be traced to sources that would release actinides. The particulate is constantly being deposited through gravitational settling and turbulent diffusion.

As part of the FY99 work, we performed an analysis (one of the sensitivity analyses) that calculated particulate matter concentrations at the fenceline from resuspension from Site soils. Using 1996 meteorological data, we calculated an annual average total particulate level of 5 to 6 micrograms per cubic meter ($\mu g/m^3$) along the east fenceline. For comparison, the total suspended particulate

(TSP) levels monitored by the Colorado Department of Public Health and Environment (CDPHE) along the same stretch of Indiana in 1996 showed an annual average of 36 to 38 $\mu g/m^3$ TSP. Based on these values, the "contaminated" particulate would be less than 15% of the TSP measured over the year at these nearby locations (i.e., the contaminated soils would be diluted by 85%).

With respect to size segregation during transport, we suggested that this might be a factor in the apparent dilution of actinide concentrations in particles on vegetation relative to the underlying surface. As the reviewer points out, this could also have the opposite effect. At present, the data available concerning particle transport to grass surfaces at the Site is insufficient to determine how this factor influences the concentration of actinides on vegetation surfaces.

Comment: Section 2.2.2, page 2-8. The assumption that erosion from bare soil as a source term for resuspension is minimal while vegetation is considered to be the major dust source is not convincing. The obvious question is just how does the vegetation become contaminated? Langer's work needs more elaboration to determine whether it is relevant. Did Langer contaminate the leaf surfaces before subjecting them to the wind tunnel or were they contaminated naturally?

Response: Based on the material developed for the FY99 study, it seems that resuspension from plant surfaces may be a chronic, low-level source of dust and actinide emissions. An important caveat here is that this resuspension mechanism is likely only important as a chronic, low-level emission source (chronic, non-anthropogenic emissions were the focus of the FY99 work). High wind events or active disturbance (which will be examined in the FY00 scope) would resuspend far larger amounts of dust and actinides, much of it directly from the soil surfaces. Over the long term, however, the chronic component must be considered since it may be the only significant mechanism at work at low wind speeds (and therefore under conditions that should not result in **any** resuspension according to most other equations).

The areas of the Site that have the highest radionuclide contamination are well vegetated. Past wind tunnel studies at the Site showed that the threshold wind speed necessary to get particles resuspended from undisturbed areas was quite high (>35 miles per hour [mph] at ground level; equivalent to > 100 mph at 10 m). Consequently, resuspension events involving the soil surface are relatively rare in the most contaminated areas (limited to a few hours/days per year).

In contrast, dust and actinides on vegetation surfaces near the top of the canopy will be more susceptible to resuspension. This meshes with Langer's observations about low-level, chronic resuspension that seemed to occur at wind

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speeds much lower than the threshold velocities calculated to move particles off the ground.

As the reviewer notes, however, there are many unanswered questions concerning this phenomenon. Ongoing deposition of suspended dust (from regional as well as local sources) is an obvious source of **dust** deposition to plant surfaces but does not necessarily explain where **actinides** in the dust would come from. Rainsplash, surface soil attached to growing plants, and resuspension from bare soil patches or other nearby disturbed surfaces are probably all sources of actinides on vegetation but are difficult to quantify.

Langer's observations about chronic, low-level emissions and his conjecture that resuspension from vegetation may be involved resulted from a multi-year ambient air sampling/monitoring program in an area just east of the 903 Pad. Vegetation surfaces were not artificially contaminated. Langer's observation that airborne actinides could be measured under low wind speed conditions was important because it contradicted expectations developed from the prevailing saltation/threshold wind speed theory of particle resuspension. Both Langer's experiments (described in Section 2.2.1 of the FY99 report) and later wind tunnel studies performed by Midwest Research Institute indicated that saltation does not occur from undisturbed bare soil at the Site under low wind speeds (as noted previously, the threshold appears to be >35 mph at ground level). No alternative explanation for Langer's observations about airborne actinides under low wind speed conditions has been proposed.

Comment: Page 2-9, 4th paragraph. The authors have now stated that both wind resuspension from bare soil and raindrop splash are not important in transporting actinides to plant surfaces. If these are not important then the processes that are important need to be identified.

Response: It was not the intent of the authors to imply that rainsplash is not important in transporting actinides to plant surfaces. As noted above, rainsplash, surface soil attached to growing plants, and resuspension from bare soil patches or other nearby disturbed surfaces are probably all sources of actinides on vegetation but are difficult to quantify. The reviewer's conjecture that road dust may be an important factor also has merit.

From a practical point of view, it is not necessary (although it would certainly be desirable) to fully understand the phenomenon to successfully apply the model as long as resuspension rates are correctly estimated. The wind tunnel data that were used to generate a chronic resuspension emission estimation technique for the Site were taken over vegetated surfaces that are relatively representative of areas of surface soil contamination at the Site. As a result, although the data used to generate the resuspension equation do not distinguish between the release of dust

(and actinides) from vegetation, from litter, and from soil surfaces, they should provide an appropriate basis for the modeling of resuspension in the absence of disturbance or excessive winds.

Comment: Page 2-9, 5th paragraph. If one assumes, as the authors do, that all of the dust on vegetation surfaces is resuspended during a fire, then I do not see that a "model" of emissions from fires is necessary. Maybe I am missing something here.

Response: The reviewer is confusing fuel load with emissions. Dust attached to vegetation is a function of the total mass of vegetation in an area; during a fire, only a portion of this organic material is released to the air (as ash). The assumption was made that dust attached to vegetation would be carried along with the resulting ash proportionally; that is, at the same concentration (pCi/g vegetation and litter (fuel) = pCi/g ash [particulate emissions]). Consequently, calculation of actinide emissions from a fire requires a calculation that converts total fuel load to airborne particulate emissions.

Comment: Section 2.3, Soil Resuspension Emission Estimation Approaches. My personal philosophy about models is that one is as good as another as long as it 1) generally does what you want it to (i.e., that you understand the processes and mechanisms well enough that you can choose a model that represents them), 2) that you understand the model's limitations, and 3) that you have good data to initialize and validate the model. Unfortunately, rarely are all of these requirements met so that a lot of arbitrary decisions (educated guesses) must be made about one or more of the above factors. Therein lies the problem with models in my opinion.

Response: The reviewer does a good job of pointing out the weaknesses inherent in any modeling approach; that is, rarely do you have all the detailed data you need to perfectly simulate a natural phenomenon, using a model that is by necessity a simplification of a complex, natural system. However, models offer the only tool by which future events can be examined. If the model limitations are correctly understood and the models are correctly applied, very good comparative data can be obtained on alternate actions (for example, alternate remediation techniques or the imposition of a specific control technology to a project). The existence of measurement data obtained under comparable conditions to that being simulated by the model greatly increases the value of the predictive approach and considerable insight into the phenomena being modeled can be derived. Fortunately, the Site has collected data on actinide concentrations in ambient air for many years, which provides a database against which to measure and understand the model's behavior.

Comment: It is not clear just what data in Figure 2-3 were used in developing the equation or whether the correlation coefficient describing how good the fit was were significant.

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Response: As stated in the FY99 report, the OU3 data only were used to develop the emissions equation. The data sources for Figure 2-3 are listed in Table 2-2. The correlation coefficient for the derived equation was 0.88.

Additional data are being taken in 2000 in conjunction with a prescribed burn in the west Buffer Zone, using the same wind tunnel configuration that was employed in the 1993 OU3 study. This study should yield additional data that can be used to refine the estimates.

Comment: Section 2.4. Emissions Estimation Method for Wildfires. There needs to be some discussion of what is known about organic versus inorganic content of smoke and combustion gasses. If 100% of the actinide contaminated soil on vegetation is assumed to be emitted, then all the discussion about models for estimating emissions is irrelevant in my opinion.

Response: Research does not seem to have been conducted previously on the potential emission of mineral soil during wildfires or prescribed burns. Data collection that would examine this issue was planned in conjunction with a proposed prescribed burn at the Site in the Spring of 2000. However, because only a test burn was conducted this year, adequate sampling was not possible. If a larger scale prescribed burn is conducted in 2001, samples will be collected that will hopefully address this question.

The Bureau of Land Management (BLM)/U.S. Forest Service (USFS) models are needed to calculate particulate emissions from a fire, as discussed previously.

Comment: Section 2.4, continued. I think the concept of "dilution of activity" as used in this report is wrong. Where is the advective soil coming from? All assumptions about source of actinides and dilution of activity is premature. Relevant data needs to be collected to conceptualize the processes with much more certainty.

Response: As discussed previously, there are ample regional and local sources of fugitive dust and particulate matter that are uncontaminated with actinides other than naturally occurring uranium. A portion of this ambient airborne particulate matter is continually being deposited on plants and other surfaces at the Site. However, we agree with the reviewer that definitive data concerning the sources of dust and actinides on vegetation at the Site are not available at this point.

Although a complete understanding of the processes involved is not necessarily required to build a useful model, the degree to which "dilution" occurs is particularly important because it directly affects the inferences regarding model performance that are drawn from comparisons with measurements of actinides in the ambient air. Hopefully, additional data concerning this phenomenon can be obtained.

Comment: Section 2.4, continued. A major question I have concerning roads as a source of actinides is whether anyone has measured actinides in barrow or road surface soils. Also, my understanding is that past remediation activities have led to elevated plutonium concentrations in east perimeter air monitoring locations. It seems like actual emission data could be obtained for some of these past remediation events. I think the EPA methods described will be pretty much worthless as a tool for predicting actinide migration at RFETS because remediations will have elaborate control technologies in place that will obviate the applicability of the EPA equations.

Response: We agree with the reviewer that it would be worthwhile to determine whether measurements of actinides in road surface soils have been made, particularly in the vicinity of the 903 Pad.

With respect to past remediation events, emission rates of actinides have been calculated for several, often using a dispersion model to back calculate emissions from perimeter monitoring data. These are interesting exercises but do not directly help with future events since the circumstances surrounding, for example, T-3/T-4 or the 774 clarifier tank draining projects, are unique. For future remediation projects, the U.S. Environmental Protection Agency (EPA) methods described in the FY99 report can be used to calculate base emissions assuming no controls. Expected control technologies can then be applied as correction factors to these base emissions, to estimate actual emissions to the atmosphere.

Comment: Section 3.0. Dispersion and Deposition Modeling. The authors assumed the release height at the soil surface but in Section 2.0 make the case that the source is vegetation surfaces which presumably stand some distance off the ground surface.

Response: The reviewer is correct that the model input assumed a groundlevel release. While not strictly correct for most of the Site, the small increase in release height that could be made to correct for the height of vegetation (mostly grassland) would have little effect on the predicted concentration or deposition values (model predictions are not that sensitive to small changes in release height).

Comment: Section 4.2.1. Pu-239 Concentrations Using Background (Fallout) Activity Level. It would seem to me that the crux of the overprediction problem is that the source term assumptions are too conservative (i.e., wrong).

Response: We also believe that a good part of the overprediction is due to an overestimated source term. However, part of the conservatism is probably due to the ISCST3 model formulation, which has a bias toward overprediction. In addition, as discussed in the FY99 report, Gaussian plume models are most accurate in simulating single, elevated (i.e., stack) sources in flat terrain. Simulations involving multiple groundlevel area sources, in rolling terrain, have a wider margin of error. As discussed previously, that doesn't mean that the model simulation is useless as a planning tool; it simply means that comparative

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information about different model simulations and about how the simulations compare with measured data is important in determining what the model results mean.

Comment: Section 5.1 Emission Estimation. Just for fun, I think it would be instructive to use the measured concentrations of dust and actinides at the perimeter air monitoring locations. Plug them into the dispersion model and then back calculate the emission rate that will produce the air concentrations. I think at least some of the overprediction is due to the assumption that resuspended particles are of the same relative distribution as in the soil. The assumption of dilution begs the question of just where this material is coming from. Just what lies upwind of the 903 Pad and is it a likely source of dust for deposition on 903 Pad area vegetation? I am not convinced that the Industrial Area is not an important source of actinides.

Response: First, particulate measurements at the fenceline cannot be used to back calculate emissions from the Site because many other local and regional sources contribute particulate to the ambient air at these locations. Only plutonium and americium are effective "tracers" for Site emissions (even uranium measurements are confounded by naturally occurring uranium in the soils).

Second, Langer essentially used such a method to calculate his generic resuspension rate, described in Section 4.2.2 of the FY99 report. Using ISCST3 to simulate dispersion, this generic resuspension rate reproduces fenceline concentrations of plutonium fairly well (within the same order of magnitude). Unfortunately, Langer's single rate does not lend itself to exploring time-dependent or short-term emission events, nor does it allow for spatial variation of emissions.

With multiple sources, such as were used for the FY99 simulations, the emission rates for each source area cannot simply be back calculated from fenceline concentrations. A correction factor that can be applied **equally** to all sources, however, can be estimated because on a source–by–source basis, the predicted concentrations are linear with emission rates. So, for example, if dilution were the only factor considered, the model results would indicate that each source should be diluted by a factor of 10 to 100 to correctly simulate fenceline concentrations (which are overestimated by 10 to 100).

As noted previously, assumptions concerning particle size distribution and actinide concentrations were taken from ambient air data and do not necessarily reflect the same distribution as occurs in the parent soil.

With respect to what lies upwind of the 903 Pad, in a very real sense, the entire Denver metropolitan area does. Regional sources of particulate matter include

traffic, industrial operations, and fugitive dust sources such as sand and gravel operations and quarries (for example, there is a sand and gravel operation located at the west fenceline of the Site that creates dust emissions, some of which deposit on Site soil and vegetation). Regionally, as well as locally, traffic is the largest source of particulate emissions.

With regard to the Industrial Area as a source of actinide emissions, ongoing ambient air monitoring at the Site provides some insight. The fenceline monitors along the east boundary of the Site (in the prevailing wind direction from the Site) show average Pu-239/240 concentrations in the 10^{-6} to 10^{-7} picocuries per cubic meter (pCi/m^3) range over the past several years. The monitor located just east of the 903 Pad (S-107) provides Pu-239/240 concentrations in the 10^{-5} pCi/m^3 range (see Table 4-1 in the FY99 report for 1996 data for this and a collocated monitor, S-007). Several monitors located within the Industrial Area that have been used over the past two years to monitor building decontamination and decommissioning (D&D) show average Pu-239/240 concentrations in the 10^{-6} pCi/m^3 range. Therefore, on an ongoing basis in recent years, it appears that both the Industrial Area and the 903 Pad are sources of airborne actinides but resuspension from the 903 Pad area is the stronger source.

Reviewer #2

Comment: The deposition process and how it is modeled were not described in detail.
Response: This description will be added in the FY00 report.

Comment: Many of the parameter values that were used have an inadequate scientific basis.
Response: Clearly, one of the weaknesses of the model as currently configured is that definitive values are not available for all parameters. Because a full data set is required for any model run, assumptions have been made as needed to allow the work to go forward. The FY99 work involved searching for available data, choosing the most appropriate for modeling, and identifying data gaps. FY00 work will fill in some of those data gaps but will probably also recommend additional work that would improve the model's precision and accuracy.

Comment: Present data appear inadequate to explain the model's overpredictions. Careful scientific analysis or use of a calibration factor to correct model results may be required.
Response: Several factors have been identified that will bring the model results closer to measured values. However, some overprediction will likely still remain, partly because of the model formulation's inherent bias toward overprediction (ISCST3 was designed for use as a regulatory model and, as such, has a bias towards conservatism; i.e., overprediction). The results of modeling various scenarios (FY00 scope) will be discussed in the context of the apparent overprediction and with respect to possible "calibration factors".

Comment: More comparisons between model predictions and observations should be made. Predicted deposition rates should be compared to measured deposition rates, if available.
Response: The comparisons that were made in the FY99 report used all the Radioactive Ambient Air Monitoring Program (RAAMP) data that were available for the meteorological data year used, 1996. The FY00 report will present a comparison of the FY99 modeling results to longer-term RAAMP data, which should refine the comparison.

Deposition measurements that are suitable for comparison with model predictions have not been taken at the Site. However, EPA chose the deposition algorithm used by ISCST3 as the best available at the time after an extensive analysis of deposition research. An optimized version of this deposition algorithm has since been developed by EPA and will be used for the FY00 modeling.

Size distribution data are available from limited studies at the Site. These data will be useful during application of the deposition algorithm.

Comment: Measurements of the dilution of dust on plants, relative to underlying soils, would be relatively easy to perform and should be considered.

Response: The relationship of the activity in dust on plants to underlying soils is important because it directly affects the comparison to measured values that was performed in the FY99 work. This factor may be a relatively significant component of the overprediction of 1996 measured values and is likely to be the factor most amenable to refinement. The FY00 report will recommend that such measurements be considered to allow for further refinement of the long-term modeling of resuspension from the Site.

Comment: The authors seem fixed on the idea that it is mainly resuspension from plants that gives rise to the general resuspension of particles into air. How do the plants get surficially contaminated? There must be an ongoing source of aerosol deposition to the plant surfaces. I would avoid hanging my hat too heavily on the plant resuspension idea, even though it is no doubt a real phenomenon.

Response: Based on the material developed for the FY99 study, it seems that plant surfaces may be a chronic, low-level source of dust and actinide emissions. However, it is a misconception to say that this phenomenon is mainly responsible for the general resuspension of particles into air because it is likely only important as a chronic, low-level emission source. (Note that chronic emissions were the focus of the FY99 work, which may explain why the report produced this misconception.) High wind events or active disturbance (which will be examined in the FY00 scope) would resuspend far larger amounts of dust and actinides, much of it directly from the soil surfaces. Over the long term, however, the chronic component must be considered since it may be the only significant mechanism at work at low wind speeds (and therefore under conditions that should not result in **any** resuspension according to most other equations).

As the reviewer notes, there are many unanswered questions concerning this phenomenon. Ongoing deposition of suspended dust (from regional as well as local sources) are an obvious source of **dust** deposition to plant surfaces but do not necessarily explain where **actinides** in the dust would come from. Rainsplash, surface soil attached to growing plants, and resuspension from bare soil patches or other nearby disturbed surfaces are probably all sources of actinides on vegetation but are difficult to quantify.

From a practical point of view, it is not necessary (although it would certainly be desirable) to fully understand the phenomenon to successfully apply the model as long as resuspension rates are correctly estimated. The wind tunnel data that were used to generate a chronic resuspension emission estimation technique for the Site were taken over vegetated surfaces that are relatively representative of areas of surface soil contamination at the Site. As a result, although the data used to generate the resuspension equation do not distinguish between the release of dust

(and actinides) from vegetation, from litter, and from soil surfaces, they should provide an appropriate basis for the modeling of resuspension in the absence of disturbance or excessive winds (provided the apparent overprediction of the model can be satisfactorily resolved).

In addition, the wind tunnel studies being performed in 2000 in conjunction with the prescribed burn in the west Buffer Zone may yield additional data that can be used to refine the estimates. Wind tunnel measurements will be taken in unburned areas to provide a control against which to judge the post-burn measurements. At a minimum, these measurements will add more data points that can be used to refine the emission equation. The new wind tunnel studies are particularly relevant because the soil and vegetation types in the prescribed burn area are consistent with those surrounding the 903 Pad. In addition, the new wind tunnel has incorporated additional sensors that will give a more complete picture of how wind affects resuspension. These observations may revise the conceptual picture of how dust and actinides are resuspended from undisturbed, vegetated surfaces on Site.

Comment: There are many instances in the report where the parameters used in the models are not evident. For example, how was deposition calculated and what parameter values were used?

Response: As noted previously, a more detailed explanation of deposition and the parameters chosen will be provided in the FY00 report. For further information regarding the calculation of deposition within the ISCST3 model, the reader is referred to EPA, 1995a. *User's Guide to the Industrial Source Complex (ISC3) Dispersion Models. Volume II—Description of Model Algorithms.* Sections 1.1.6.3 and 1.3.

Comment: Modeling results for air concentrations are given as a range. Was this based on Monte Carlo sampling, or what? What do the ranges mean in terms of percentiles? Why are the deposition results given as single estimates whereas the air concentrations that drive deposition are given as ranges?

Response: The presentation of the air concentrations as ranges is an artifact of the visual presentation technique chosen and does not imply anything beyond that. Monte Carlo sampling was not done; all results were point estimates (deterministic, rather than stochastic). As noted in the report, deposition and concentration model runs were performed separately because of excessive run times for the deposition simulations. The deposition simulations used a receptor grid that spanned the Site and areas beyond, while the concentration runs focused on receptor locations around the fenceline. The deposition results therefore lent themselves to presentation as isopleths. The concentration values were summarized by presenting ranges of values as colored, closely spaced dots around the perimeter of the Site, which is why they appear to be given as a range, rather than single estimates.

Comment: Page ii. 3rd paragraph. Ultimately, the plants have to get the contamination from the soil. So, I would argue that the soil surface is the primary reservoir and the ultimate source.

Response: We agree that the soil surface is the ultimate source of the actinide contamination seen on plant surfaces.

Comment: Page iii, 4th paragraph. The "site-specific resuspension factor" is referred to. This number, and units, should be given.

Response: Details of the Site-specific resuspension factor (or rate) are given in Section 4.2.2. The value is 2×10^{-12} sec^{-1}.

Comment: Page iii, last paragraph. What is meant by "double counted"? I don't follow the concept.

Response: By double counted, we mean that the mass of particulate (and associated actinide) that is calculated as deposited to the ground in the deposition runs was not removed from the plume in the concentration runs. Therefore, the same mass (and activity) was counted twice; once as grams (and pCi) deposited and once as grams (pCi) still in the air.

Comment: Page 2-6, 3rd paragraph. The density assumed for soil particles of 2.5 g/cm^3 is probably too high, maybe even by a factor of 2 in some cases. Much of the surface soil is comprised of aggregates of mineral grains and organic material. It would be nice to make some careful measurements of the actual density of different sized particles from surface soils at the RFETS.

Response: We've refined the assumptions somewhat for the FY00 modeling. As the reviewer notes, some of the particles may be less dense aggregates, rather than pure mineral soil. Based on a theoretical breakdown of size fractions and densities for generic soil given in Foster, G.R., G.C. White, T.E. Hakonson, and M. Driecer, 1985. *A Model for Splash and Retention of Sediment and Soil-Borne Contaminants on Plants.* Transactions of the ASAE, 28(5), p. 1512, the size fractions will be modeled as follows:

- <3 μm, 2.65 g/cm^3 (assumed primary clay particles);
- 3-15 μm, 2.65 g/cm^3 (assumed primary silt particles); and
- >15 μm, 1.8 g/cm^3 (assumed small aggregates).

This breakdown is consistent with soil specific gravity data taken in the Woman Creek drainage and near the South Interceptor Ditch on Site.

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Comment: Page 2-6, Table 2-1. Langer is cited as the source for the mass and Pu activity fractions. There are other data on this as well. It might be useful to compare with other data since these values could be based on a handful of soil at a specific location, and I suspect substantial spatial variability.

Response: The data cited and used in the model are based on air sampling to the east of the 903 Pad, at a 1 meter height. These data were used for the mass and activity fractions, rather than surface soil data, because what becomes airborne may not precisely match the mass and activity fractions in the surface soil itself. For example, some size fractions include both primary mineral soil particles and aggregates. It is possible that aggregates are preferentially resuspended, rather than mineral soil, because the particles are less dense.

As part of the literature review performed for the FY99 work, other monitoring studies of airborne particulate that were performed at the Site were examined. Many studies did not look at actinide activity based on particle size and several that did examine particle sizes used samplers that were later shown to have problems with particle loss or incorrect fractionation. Langer's long-term study therefore appeared to provide the best, most consistent database for these values. However, soil data from the Site will be examined further in FY00 to determining whether the assumptions made about particle density should be refined.

Comment: Page 2-8, 2nd paragraph. It is indicated that plant litter is not readily accessible for resuspension. I don't believe this, especially in winter-spring when standing biomass is low and winds are high.

Response: The reviewer is undoubtedly correct that litter is resuspended, especially in high winds and during winter and spring when the vegetation canopy is reduced. During many hours of the year, however, litter may be well down in the boundary layer where winds speeds are low because any standing biomass (dead or live) will increase surface roughness. Our point should have been that the source of dust resuspension during these low wind speed periods might be primarily dust on vegetation surfaces in the canopy, where wind speeds are higher.

Comment: Page 2-9, last paragraph. Can the references be provided on the USFS and BLM studies on release of particulate matter by fires?

Response: See Andrews and Bevins, 1998; Sestak and Riebau, 1988; and Ward, et al., 1996 in Section 6.0 Bibliography. Copies of these publications can be made available to the reviewer if desired.

Comment: Page 3-12, 2nd paragraph. I think a stochastic modeling approach that considered the variables mentioned, as well as the probability of a fire vs. time of year, would be useful.

Response: A reasonable "worst case" approach will probably be used for the FY00 modeling; however, the reviewer's comments offer an excellent suggestion for further investigation should the FY00 scenario results warrant further study.

Comment: Page 3-18, Table 3-3. Are the maximum estimated doses annual doses? This is not clear. Also, to be nit-picky, mrem is not a unit of dose.

Response: Yes, the concentrations and "doses" given in Table 3-3 are annual values. The FY00 report will clarify that mrem is a unit of effective dose equivalence (EDE).

Comment: Page 4-2, Figure 4-1. It is a pity that air monitoring data for the point of maximum predicted air concentrations on the east fenceline are either not given or are not available for some reason. I would want my comparisons to reflect conditions in or very near the plume centerline if possible.

Response: No monitoring data are available from the predicted point of maximum impact for 1996. The monitoring locations shown in Figure 4-1 are the only fenceline sampling locations that were subjected to routine isotopic analysis in 1996. Data are available for additional fenceline locations in other years, however. As noted previously, these long-term data will be compared to modeled values in the FY00 report.

Comment: Page 4-7. The discussion about the effects of vegetation cover seems to ignore the fact that plant cover is very dynamic and varies greatly over the seasons.

Response: We agree, although the general discussion is still valid as a comparison between the period when the wind tunnel and airborne mass/activity fraction data were taken and present conditions.

Comment: Page 4-15, first paragraph below bullets. It says that only snow cover over the ground causes resuspension to cease. What about a more typical light snow cover over the ground when vegetation protrudes above the snow cover? If this condition stops resuspension, then the argument about vegetation being the primary source falls apart.

Response: We agree that such information could potentially provide additional insight into the resuspension phenomenon; however, Langer's reports of his observations weren't detailed enough to determine the amount of snow cover necessary to stop resuspension. It is also worth noting that snow cover is a relatively small factor in the annual emission estimation algorithm and is taken into account in a rather crude fashion—it is simply used as an on/off switch to exclude hours when significant resuspension would be unlikely to occur even if strong winds were present.

Reviewer # 3
(Sumner Barr, Los Alamos National Laboratory)

Comment: Section 2.a. We need to be careful in extrapolating to hourly rates from short-term wind tunnel observations because we may underestimate the resuspension rate.

Response: The reviewer points out that while a surface may have adjusted to a wind gust from one direction, it will be vulnerable to enhanced resuspension from another direction and that the wind tunnel cannot capture these physics. Hence the above comment.

We agree that the wind tunnel cannot capture the effect of gusts from varying wind directions, and that not accounting for such phenomena could result in underestimates of resuspension. In the current study, our resuspension methodology was based on the steady-state assumption of constant resuspension of particles for a given hour, based on the average wind speed for that hour. As described in Section 2.3.3 of the FY99 air pathway report, the wind tunnel data (representing the resuspension flux for an exposure less than 1 hour) were adjusted to reflect the flux after an hour's exposure to match the hourly time step of the dispersion model used. Not making such an adjustment would clearly have resulted in overly conservative fluxes and concentration/deposition estimates.

The question arises as to whether use of a constant resuspension flux for a given hour, based on the hourly wind speed, would lead to under- or overestimates of the particulate mass resuspended relative to a method based on wind gusts from varying directions. As discussed in the FY99 report, we believe that under normal wind speed conditions resuspension occurs primarily from vegetation (grass blades) and litter, as opposed to an exposed soil surfaces, in the contaminated areas of the Site. We would expect that the varying wind direction influence would be greatest, relatively speaking, for a bare soil surface. The answer to this question is likely correlated with the magnitude of the wind gust(s) and is uncertain given the present knowledge about resuspension. However, we speculate that for gusts of "lower" wind speed, the employed approach is probably conservative.

Comment: Section 2.b and g. The preparation of meteorological inputs described in the report is conventional and for the assessment as carried out, I believe, adequate. There are a number of places in the report where a compromise was apparently made due, in part, to a lack of some essential micrometeorological data. Future monitoring programs will greatly benefit from a modest but well designed micrometeorological measurement program.

Response: With regard to the reviewer's suggestion for a micrometeorological network, we agree that such a network would help to understand the intricate dispersion

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characteristics across the Site. However, the relatively large and essentially unquantifiable uncertainties in several of the model input parameters make the practical use of such information less feasible. Instead, we have chosen to invest our limited physical study resources on better quantification, or at least better characterization of the range of the resuspension parameters and the size distribution of the radioactive components of particulate matter. These parameters were chosen for further study because current model inputs are based on a very limited data set and changes in the resulting values could be relatively important in refining model predictions. As a result, a number of wind tunnel studies have been initiated in FY00 that will provide additional data to refine source input parameters.

The air pathway has not proven to be a threat to public health over the past decade, nor do the emissions from vegetated soil contamination areas seem to be of concern based on the FY99 air pathway investigations. Understanding and demonstrating the mechanisms for resuspension are necessary to eliminate this natural pathway from consideration in future cleanup decisions, or to identify circumstances where the pathway may become important.

Comment: Section 2.c. Check what you are using in your calculations—I used the coefficient 2×10^{-8} rather than 2×10^{-9} as in the report (supporting the resuspension equation presented on Page 2-18, in Section 2.3.4).

Response: The 2×10^{-9} coefficient comes from creating a power fit to the data labeled as "from the OU3 wind tunnel study" in the Table 2-2 comment column. As the reviewer noted, we also determined that a 2×10^{-8} coefficient may be obtained from plotting a larger segment of the tabular data presented.

The data presented in Table 2-2, and shown graphically in Figure 2-3 in the FY99 report, were determined to be the data most relevant to the intent of the FY99 study; that is, the chronic resuspension of contaminated soil from an undisturbed, vegetated surface. The wind speeds were calculated from the field testing data, and represent what the ambient wind speed would be at a reference height of 10 m.

Comment: Section 2.d. No method is given for calculating Pu resuspension.

Response: As the reviewer notes, the equation presented on Page 2-18 in Section 2.3.4 provides the particulate resuspension in units of grams per square meter per second ($g/m^2/s$). This represents the particulate flux for a given hour of model execution over the entire spatial area considered a source of emissions on Site. This particulate flux was based on the hourly wind speed obtained from the meteorological data set.

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To obtain the flux in units of activity (e.g., picocuries per square meter per second, $pCi/m^2/s$), the particulate flux was multiplied by the soil activity level, defined in units of picocuries of radionuclide per gram of soil (pCi/g), for each of the source areas defined from the isopleth maps of soil activity. The FY00 report will describe this calculation in greater detail.

Comment: Section 2.e. The concept for calculating the amount of Pu in the soil is never expressed.

Response: The reviewer is correct in stating the importance of the soil activity levels to the emission estimates. In calculating the flux of activity for a given radionuclide, a uniform distribution of activity (in pCi/g) was assumed within the spatial area defined by a given contour on the map of soil activity levels. Then, as described in the preceding response, the particulate flux based on ambient wind speed was multiplied by the soil activity level (in pCi/g) to obtain the activity flux for a given source area.

Comment: Section 2.e. There isn't enough information in the report to independently estimate the source strength, except to back-calculate from the concentration fields. When I do that with some pretty gross estimates of annual plume parameters I get an average source strength of about 0.1 to 10 pCi/s. Is this close to the value used?

Response: Given its dependence on wind speed, the source strength varies hour-to-hour. Taking the median particulate flux of 8.7×10^{-8} $g/m^2/s$, identified on Page 2-19 of the report, and a low activity level of 0.1 pCi/g (Pu-239/240) and its associated area, an emission rate of 0.1 picocuries per second (pCi/s) can be calculated. Taking the highest activity isopleth (1,000 pCi/s for Pu-239/240) and its associated area, and applying it to the median dust flux, produces an emission rate of 2.8 pCi/s. The larger estimate of 2.8 pCi/s yields an annual emission rate of 8.8×10^{-5} curies per year (Ci/yr).

Comment: Section 2.h. I became curious about the emissions in a wildfire compared with the chronic resuspension source. Section 2.4 provides the formulae for making this estimation. Choosing mid-range values for the parameters in Section 2.4 gives a release of plant-borne soil particles of 5×10^{-4} $g/m^2/s$. Assuming 5 to 100 pCi/g of soil, a modest fire that burned for 1 hour and consumed 1 hectare would release a range of 0.0001 to 0.002 Ci, less than 2% of the chronic annual release.

Response: The reviewer's estimated release is too high. The emission rate of 5×10^{-4} $g/m^2/s$ that was estimated represents the total particulate matter released from a fire, rather than the plant-attached soil (emission factors presented on page 2-22 of the report were for total particulate emissions from a fire). Average soil attachment was reported on page 2-24 of the FY99 report as 18 milligrams soil per gram of plant material (mg/g). The resulting soil release would be approximately 1×10^{-5} $g/m^2/s$. However, the reviewer has also averaged the current year

production and litter biomass values across the Site (Table 2-3); instead, these numbers are additive because both current year biomass and litter will contribute to total fuel load. Using an average of litter + current year production of 314.8 g/m^2, the resulting soil release would be 2×10^{-5} $g/m^2/s$.

Assuming a contamination level of 100 pCi/g (a reasonable mid-range value for the contaminated soil areas at the Site) and a 1-hour fire that burned 1 hectare (10,000 m^2), the resulting plutonium release would be 63,750 pCi or 6.38×10^{-8} Ci (a picocurie is 10^{-12} curies).

Comment: Section 2.i. In reviewing the data I found an apparent discrepancy between samples at S-007 and S-107 that requires explanation. The two are essentially co-located yet S-007 was 17% lower than S-107 on the annual average. If we group the S-007 (monthly) data to estimate the same quarterly basis as S-107 we see that the disagreement was dominated by the period of October-November 1996 when S-007 values were less than 50% of S-107 values. This large difference seems to push the explanation based on sampler design given in Section 4.3.1.

Response: The reviewer is correct in noting that measured Pu-239/240 concentrations at the S-007 sampler were substantially lower than those at the co-located S-107 sampler during late 1996. The two samplers recorded more consistent concentrations earlier in the year and it may be that S-007 experienced some undetected malfunction during the fall months.

As noted in Section 4.3.1 and Appendix C to the FY99 report, the older sampler design (S-007) is somewhat less efficient than the newer samplers (S-107) at capturing particulates, specifically during high winds. Statistical comparisons discussed in Appendix C to the FY99 report showed that, overall, plutonium concentrations were not significantly different between S-007 and S-107 over the period October 1993 to July 1998, after which S-007 was removed from service. The exception was during months when the average wind speed exceeded 11 mph, when S-007 significantly underreported Pu-239/240 relative to S-107.

Comment: Section 2.i. The fenceline samplers exhibited different model/observed ratios. That's not a problem but it gives one pause to think about why. Notice that the annual observed concentrations are within 10% of each other so the bias difference is in the model. Figure 3-4 shows that the two sites are on the edge of the modeled plume. With the corrugated terrain in that portion of the fenceline, it's quite possible that the model underestimated the dilution effects of Woman Creek and Smart Ditch ravines.

Response: A more complete comparison of modeled and measured concentration values based on chronic, natural resuspension will be presented in the FY00 report. The enhanced comparison shows that measured Pu-239/240 and Am-241 concentrations are overpredicted in the predominant downwind directions from

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the center of the Site and underpredicted at other samplers. This finding is consistent with the pattern noted by the reviewer: the S-138 sampler is closer to the predominant downwind direction than S-207 and therefore shows a larger overprediction. Reasons for this model behavior will be explored in detail in the FY00 report.

Comment: Section 2.j. A useful part of Section 4 is the sensitivity analyses to test...statistical dependence of enhanced resuspension on strong westerly winds but not on rainfall. Some features of this result piqued my curiosity. Why the dependence on wind direction? Is that where the strongest winds come from or is the wind gustier in that quadrant?

Response: Both the strongest sustained winds and the highest wind gusts come from the westerly direction at the Site. Also, the analysis described in Section 4.3.1 and Appendix C was originally undertaken in an attempt to explain periodic spikes in Pu-239/240 concentrations at the S-107 sampler location. S-107 is located just east of the 903 Pad area, so enhanced resuspension affecting this sampler would occur during westerly wind regimes.

Comment: Section 2.k. I found Appendix B to be quite confusing and although I applied several different interpretations, I don't think I ever understood what the authors are trying to accomplish with Appendix B. My main point of confusion is what the authors mean by isopleth and isopleth centroids.

Response: The maps and tables in Appendix B were an attempt to give the reader a feeling for where the main areas of surface soil contamination are on Site. A Site soil sampling database has been used to develop maps showing isopleths of contamination—that is, a contour plot of lines of equal contaminant concentration. Isopleth centroids represent the center of contaminant mass for each isopleth. For the FY00 report, the information presented in Appendix B will be replaced with aerial photographs and map overlays showing the contamination contours directly.

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Appendix B

Revised Resuspension Modeling Background Information and Results

APPENDIX B

REVISED RESUSPENSION MODELING BACKGROUND INFORMATION AND RESULTS

This appendix presents background material concerning dispersion modeling and the process and simulation of deposition. The results of the modeling analyses performed for Scenario 1 are also presented.

B.1 Basic Modeling Concepts

Air quality models are used to estimate the concentrations of pollutants that result from emissions of pollutants into the atmosphere. An air quality model typically consists of a series of equations that relate the characteristics of an emission source to the nature of the meteorological conditions that transport the emissions through the air. Ultimately, a pollutant concentration is calculated at some point of interest distant from the source of emissions. Because air quality models fundamentally simulate the degree to which the atmosphere transports and *disperses* emissions from a source, they are generally referred to as *dispersion models*. Most dispersion models have a basic set of components in common, including parameters that represent the characteristics of the emission source, some representation of the meteorological conditions that disperse the pollutants, and coordinates at which concentrations are predicted, which are called *receptors*. Each of these basic components is described below.

B.1.1 Emission Source Parameters

An emission source is represented in a dispersion model by indicating the type of source that is being modeled and other characteristics of the source such as emission rate, height of release, and the size of the release area or the initial dimensions of the release. Sources can be classified as *stationary* sources, which are sources that operate from a single position, or as *mobile* sources, which include sources such as automobiles that release pollutants while in motion. Stationary sources can be further classified as *point*, *area*, *volume*, or *line* sources.

An example of a point source would be the exhaust stack associated with an internal combustion engine used to drive a piece of equipment such as a compressor, generator, or pump. Other point sources at the Rocky Flats Environmental Technology Site (RFETS or Site) include boilers at the Steam Plant, and various building stacks and vents.

Area sources are used to simulate releases that do not originate from a single point such as evaporation from a pond or wind erosion from earth moving activity at a construction site. Emissions such as these, which do not pass through a stack or vent, are called *fugitive* emissions. An example of an area source at the Site would be windblown dust

from the landfill. Remediation projects typically include many activities that are best characterized as area sources, such as emissions from excavation and wind erosion of bare ground areas or storage piles. Decontamination and decommissioning (D&D) will also include area source releases from building demolition.

Volume sources are used to model releases that are contained in a measurable volume prior to dispersion, such as the cloud of particulate matter that forms above a cooling tower. Line sources are often used to represent emissions from an elongated shape such as an unpaved road.

For each type of source, the height of release is input to the model. For point sources, this is merely the stack height, while for area or volume sources, this is the height of the release area or the height of the center of the volume. The size of a source is expressed as the stack diameter for point sources, and the actual or expected dimensions of the release for an area or volume source. Point sources are further characterized by the *exhaust temperature* of the release, and the magnitude of the flow of the exhaust, which is expressed as an *exit velocity*.

The portion of air that contains pollutant material from a continuous release is called a *plume* and the movement and dispersion of the plume is what the model simulates. The height that a point source plume rises above its point of release is called the *plume rise*. Plume rise is derived through consideration of the buoyancy that is provided by the temperature of the exhaust gas and the momentum that is generated by its exit velocity. By combining the plume rise with the release height for a plume, the model determines the *plume height*. It is from this plume height that the model begins the dispersion of the plume through the atmosphere. In general, the higher above the ground that a plume begins dispersion, the lower the resulting groundlevel pollutant concentrations will be because the plume must disperse over a longer distance before it touches the ground. Plume rise and initial plume dispersion can be affected by turbulence that is created by winds blowing over and around buildings and other obstructions near the release point of a plume. This phenomenon is called building wake effect, or more commonly, plume *downwash*.

Source emission rates are typically expressed as a mass per time, such as grams per second (g/s). For an area source, the emission rate would be expressed as mass per time per area, or grams per square meter per second ($g/m^2/s$).

B.1.2 Meteorology

The amount of data required to represent meteorological conditions in a dispersion model will vary according to the degree of sophistication of the model. *Wind speed* and *wind direction* are fundamental properties that appear in some form in all dispersion models. While wind direction determines the direction of pollutant transport, the wind speed

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determines the rate of pollutant transport. For a continuous emission release, the concentration of a pollutant in the atmosphere will be inversely proportional to the wind speed. As the wind speed increases at an emission point, a greater volume of air is available through which to distribute the emitted pollutant. As a result of the higher winds, the emitted pollutant is distributed through a greater volume of air and the concentration of the pollutant in the air is proportionally lower. Because wind speeds typically increase with height above the ground, wind speeds that are measured at a height that differs from the height of pollutant emission must be corrected to represent the wind speed at the height of release. This correction is done with an equation that relates the profile of wind speeds at different heights to the amount of obstruction to flow near the surface and the *stability* of the atmosphere.

Atmospheric stability is a parameter that also influences the rate of dispersion of pollutants. Stability can be thought of as a measure of the turbulence in the atmosphere. As the atmosphere becomes less stable, the amount of turbulence increases. An example of this effect can be seen on a sunny, hot summer morning as the sun rapidly heats the ground surface. The air near the surface becomes more buoyant as this heating progresses and the air then rises and is replaced with cooler air from above. The turbulent swirls of air that result will bring greater volumes of cleaner air that can mix with pollutants and produce lower concentrations. Stability within dispersion models is often represented as discrete categories, representing a spectrum of conditions from very stable to neutral to very unstable. An amount of pollutant that is released into a very unstable atmosphere is allowed within the model to mix with a larger volume of air. On the other hand, an amount of pollutant released into a very stable atmosphere is contained within a smaller volume, and the concentration is therefore higher.

Frequently there is a limit to the extent to which a pollutant can disperse in the vertical direction. This limit is called the *mixing height*, and is defined as the height above the surface through which relatively vigorous vertical mixing occurs. Within a dispersion model, the mixing height is treated as a barrier above which the plume cannot disperse, or can only disperse in a limited manner.

Some models estimate the dispersion of a plume with meteorological conditions that were measured at a single station, and these conditions are assumed to apply throughout the entire area being modeled. An example of this type of model is the U.S. Environmental Protection Agency's (EPA) Industrial Source Complex Short-Term (ISCST3) model. Other models with a greater degree of complexity require a full 3-dimensional representation of the wind field through which a plume will be dispersed. For these models, meteorological data from several locations is required, as is data from various levels above the ground surface (obtained from *upper-air soundings*).

More sophisticated models that contain equations that simulate chemical reactions in the atmosphere may require additional meteorological parameters such as *relative humidity*

and *solar radiation*. Models that estimate that amount of *deposition* of particles or gases to the ground surface may require more sophisticated or more detailed representations of atmospheric turbulence near the surface.

B.1.3 Modeling Receptors

The equations within most dispersion models combine all of the information on source characteristics and meteorology to arrive at an estimate of pollutant concentration at a particular point in space called a *receptor* (with the exception of grid models). A receptor can be represented by its 2-dimensional position in space (e.g., its coordinates along the x [east-west] and y [north-south] axes), or it can be represented by its position along the x, y, and z axes, with the z position being the elevation of the receptor. Many models can simulate the movement and dispersion of pollutants over or around terrain features, and for these models the receptor elevation is an important parameter. Receptors are typically placed in *Cartesian* or *polar* receptor grids. Cartesian grids include arrays of points identified by their x and y coordinates. The positions of receptors in a polar receptor grid are represented by their direction and distance from the origin of the grid.

Figure B-1 presents an example of a Cartesian receptor grid, and Figure B-2 presents an example of a polar receptor grid. Figure B-1 is a Cartesian grid with receptor spacing that increases with increasing distance from the source being modeled. Within 1 kilometer (km) of the source, the receptor spacing is 100 meters (m). Beyond that, the receptor spacing is 250 m. The polar grid (Figure B-2) includes receptors placed along radials at every 10 degree intervals, also with increasing receptor spacing with increased distance from the source.

B.1.4 Types of Models

Air quality dispersion models have been developed for a variety of purposes. The intent of all source-oriented models is to take the emissions produced by a particular source, or group of sources, and express those emissions in terms of air concentrations, or amount of mass deposited, at defined locations of interest. In a source-oriented modeling analysis, the emissions from each source are uniquely identified and are then dispersed and transported according to the model's formulation. Air dispersion modeling ranges from the quick application of fairly simple models to the application of complex models requiring a great deal of preparation to implement. An example of a simple application would be that of estimating the short-term impacts of a single emission point with a "screening" level model. Screening-level modeling involves simplified calculation procedures designed with enough conservatism to determine if a source of pollutants is either clearly not a threat to air quality, or poses a potential threat that should be examined with more sophisticated, or "refined," estimation techniques. Screening models are most appropriate for assessing the air quality impacts of single sources (emission points), and sources with continuous, constant emission rates.

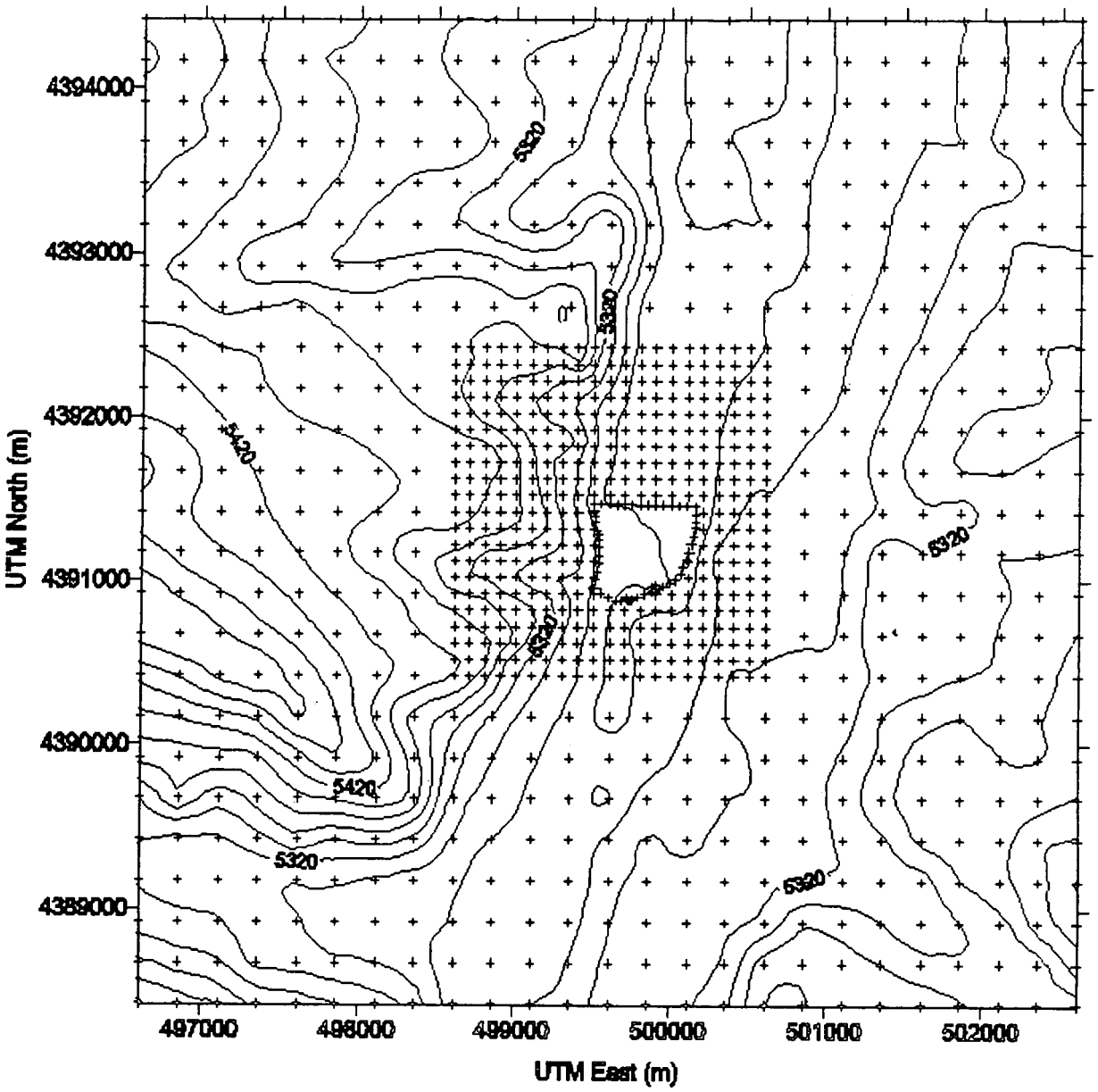

Figure B-1. Example of a Cartesian Receptor Grid

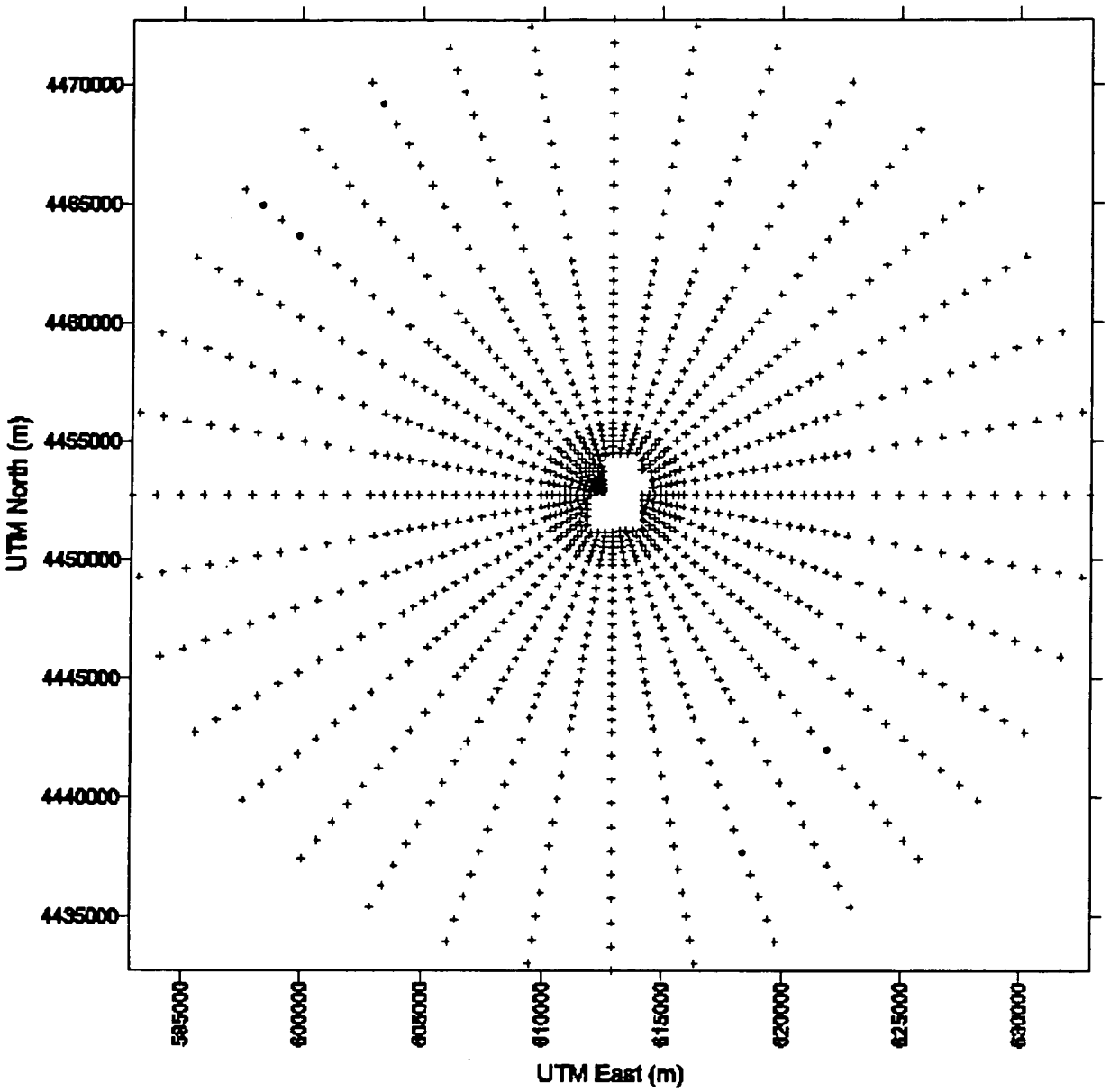

Figure B-2. Example of a Polar Receptor Grid

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A more complex, or "refined," modeling application is required to estimate the air quality impact of multiple emission points. Refined dispersion modeling requires additional detail in meteorological data, definition of a receptor grid, and greater definition of the emission sources. Consequently, refined modeling provides more accurate estimates of source impacts.

Air quality models can be categorized into four general classes: Gaussian, numerical, statistical/empirical, and physical. Gaussian and numerical models are typically used for most regulatory applications. The particular model that is chosen for a specific air quality modeling analysis will depend on the objectives of the analysis and the specific characteristics of the source(s) and its geographic setting. The primary factors to consider in selecting a model to use for a particular application include:

- The types of emission sources (i.e., stationary or mobile, point, area or volume);
- What time-averaged concentrations are desired (e.g., instantaneous, hourly, daily, or annual);
- What spatial scales are involved (local and/or regional);
- The meteorological and topographic complexities of the area are within the modeling domain;
- The importance of determining the chemical transformation of pollutant emissions;
- The level of detail and accuracy needed in the model output; and
- The quality and extent of the required input data.

Over the years, numerous models have been developed to address these various factors, with certain versatile models, such as the ISCST3 model, able to accommodate a range of attributes. The ISCST3 model, which was chosen for the FY99 and FY00 air transport pathway modeling, is a Gaussian model. Gaussian models are described below.

B.1.5 Gaussian Model Formulation

A "Gaussian" model uses a steady-state Gaussian plume equation to model emissions. This means that the emissions from the source are assumed to follow a Gaussian (bell shaped) distribution in the vertical and horizontal as they are transported downwind (see Figure B-3). Conservation of mass is assumed, and for a given time step of the model (typically 1 hour), dispersion does not vary in time or space. Plume flow is assumed to be continuous and straight line. Gaussian models are widely used because:

- They produce results that agree with experimental data reasonably well;

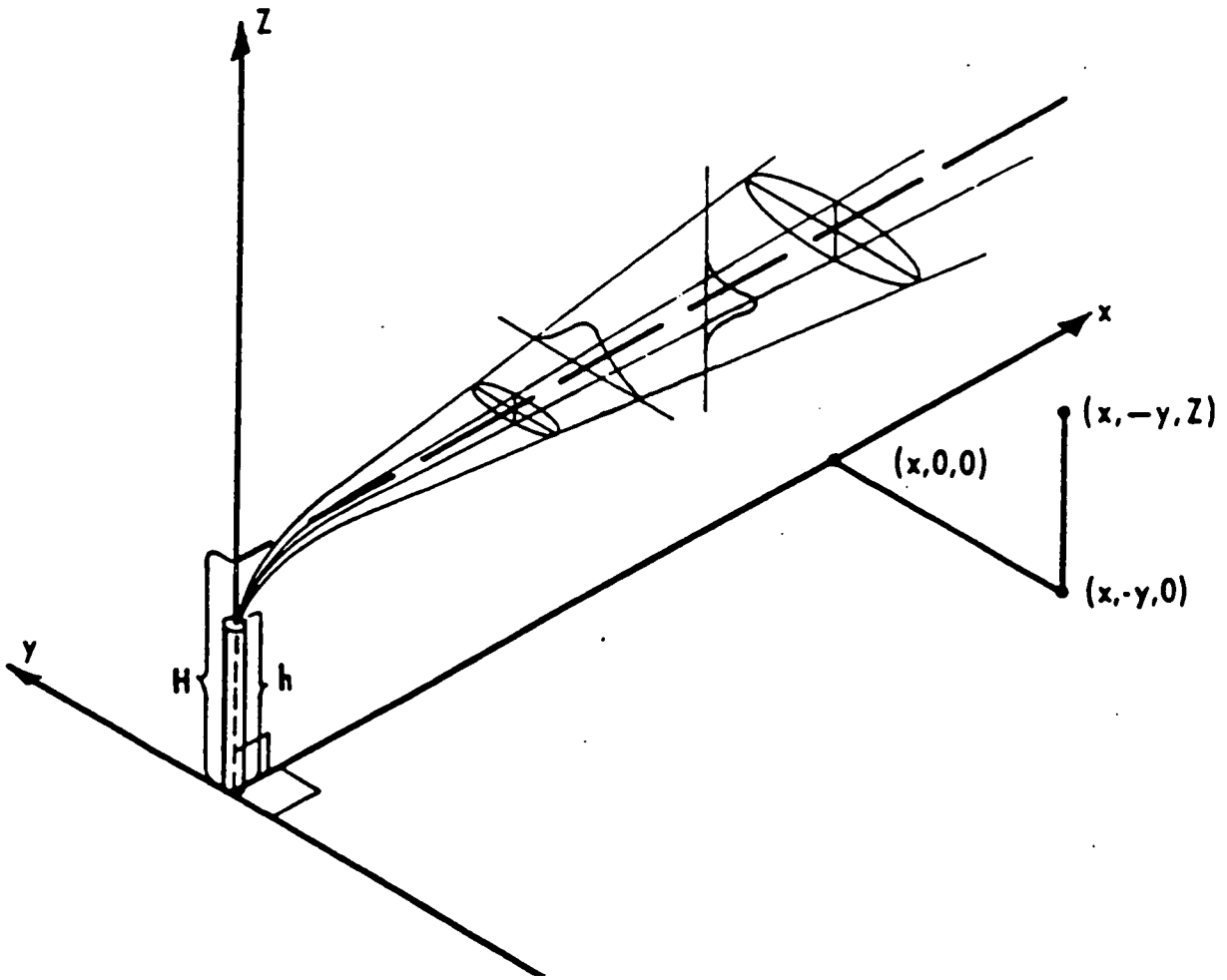

Figure B-3. Gaussian Plume Coordinate System (EPA, 1970)

- It is relatively easy to perform mathematical operations on the Gaussian equation; and
- The formulation is consistent with the nature of atmospheric turbulence (Hanna et al, 1982).

B.1.6 ISCST3

The model used for the FY99 and FY00 air pathway simulations, ISCST3, is a Gaussian plume model that is available from and maintained by the EPA. For many years, the ISC model has been the "workhorse" model for most regulatory applications, as it can accommodate multiple sources and source types, varying terrain (above and below stack height), and building downwash, and can estimate both concentration and deposition (wet or dry).

ISCST3 uses the Gaussian equation to calculate concentrations at each receptor location, from each emission source, for each hour of meteorological data provided. The total concentration at a receptor is calculated as the sum of the contributions from each source. The individual hourly concentration values at a receptor are summed and averaged to produce concentration estimates for periods longer than 1 hour, as specified by the user.

B.2 Plume Depletion and Deposition

Plume depletion refers to the removal of particles from a plume as it travels downwind and dry deposition is the deposition of particles in the absence of precipitation. "Wet" processes including rainout and washout can also result in plume depletion and subsequent deposition of particles; however, for the situations modeled for the FY99 and FY00 air pathway reports, the effects of wet deposition were expected to be negligible (EPA, 1999). Consequently, wet deposition processes were not included in the FY00 modeling analyses.

Particles in a plume are brought to the surface through the combined processes of turbulent diffusion and gravitational settling. Once near the surface, they may be removed from the atmosphere and deposited on the surface. As a plume of airborne particulate matter is transported downwind, such deposition near the surface reduces the concentration of particles in the plume, and thereby alters the vertical distribution of the remaining particles. Furthermore, the larger particles will also move steadily nearer the surface at a rate equal to their gravitational settling velocity. As a result, the plume centerline height is reduced, and the vertical concentration distribution is no longer entirely Gaussian (bell shaped).

Deposition is generally defined in terms of a *deposition flux*, which is a product of the pollutant concentration (χ_d) just above the ground surface and the deposition velocity (v_d):

$$\text{Deposition flux} = \chi_d v_d$$

The deposition flux has units of mass per area per unit time (e.g., grams per square meter per second, $g/m^2/s$, or grams per square meter per year, $g/m^2/yr$).

Deposition velocity is a function of gravitational settling, aerodynamic resistance, and deposition layer resistance, all of which vary with particle size and density. The effect of gravitational settling results in more dense and larger particles settling out more quickly (closer to the source of emissions) than lighter and smaller particles.

The effects of aerodynamic resistance and deposition layer resistance occur in different layers of the atmosphere. The lowest few meters of the atmosphere can be divided into two layers: an upper, fully turbulent region where vertical fluxes are nearly constant, and a lower, thin, quasi-laminar sublayer. Aerodynamic resistance is the resistance to particle transport through the turbulent, constant flux layer, and is a function of the roughness of the surface and the Monin-Obukhov length, an atmospheric stability parameter. Deposition layer resistance (resistance to transport through the quasi-laminar sublayer) incorporates the effects of Brownian motion, which controls the deposition rate for small particles, and inertial impaction, which tends to dominate for intermediate-sized particles in the 2 to 20 micrometer (μm) diameter size range.

As discussed in Section B.1, ISCST3 simulates dispersion using a steady-state Gaussian plume equation. At any point downwind of a source of pollutant emissions, the pollutant concentration will be a function of the initial emission rate of pollutants from the source, plume spread in the horizontal and vertical, the wind speed at the pollutant release height, and a number of other factors that affect the vertical distribution of mass in the plume. ISCST3 uses a "vertical term" to account for the effects of source elevation, receptor elevation, plume rise, limited mixing in the vertical, gravitational settling, and dry deposition of particles on mass distribution. When plume depletion and dry deposition are calculated, as was done in the FY00 modeling, the vertical term must take into account both mass removal (due to particles being deposited from the lowest portion of the plume) and gravitational settling of the remaining particles in the plume. As noted previously, both mass removal by deposition and gravitational settling are dependent on particle size and density.

To model dry deposition and plume depletion, the ISCST3 model requires that the particle size categories of interest be identified. Mass fractions are defined for each size category and must sum to unity (i.e., the total mass of particles emitted by the source must be apportioned among the particle size categories chosen). For each category, a

mean particle diameter and particle density are specified by the user. Differing particle size categories and associated particle diameters and densities may be specified for each source of emissions.

In simulating dispersion, deposition, and plume depletion, ISCST3 calculates a modified vertical term for each particle size category for each source/receptor pair. The total vertical term is the sum of the terms for each particle size category, weighted by their respective mass fractions.

As described in Section B.1, ISCST3 calculates a concentration for each hour of the simulation, at each receptor, due to emissions from each source. If calculations of plume depletion and dry deposition are requested by the user, a deposition flux is also calculated for each source/receptor pair, for each hour of the simulation. The airborne concentration at a given receptor is decreased by the amount of mass that is deposited to the surface. Total concentration and deposition at a given location are calculated by summing each source's contribution and the 1-hour values are averaged for the time periods specified in the simulation.

B.3 Model Results

Figures B-4 through B-13 show the results of the Scenario 1 modeling.

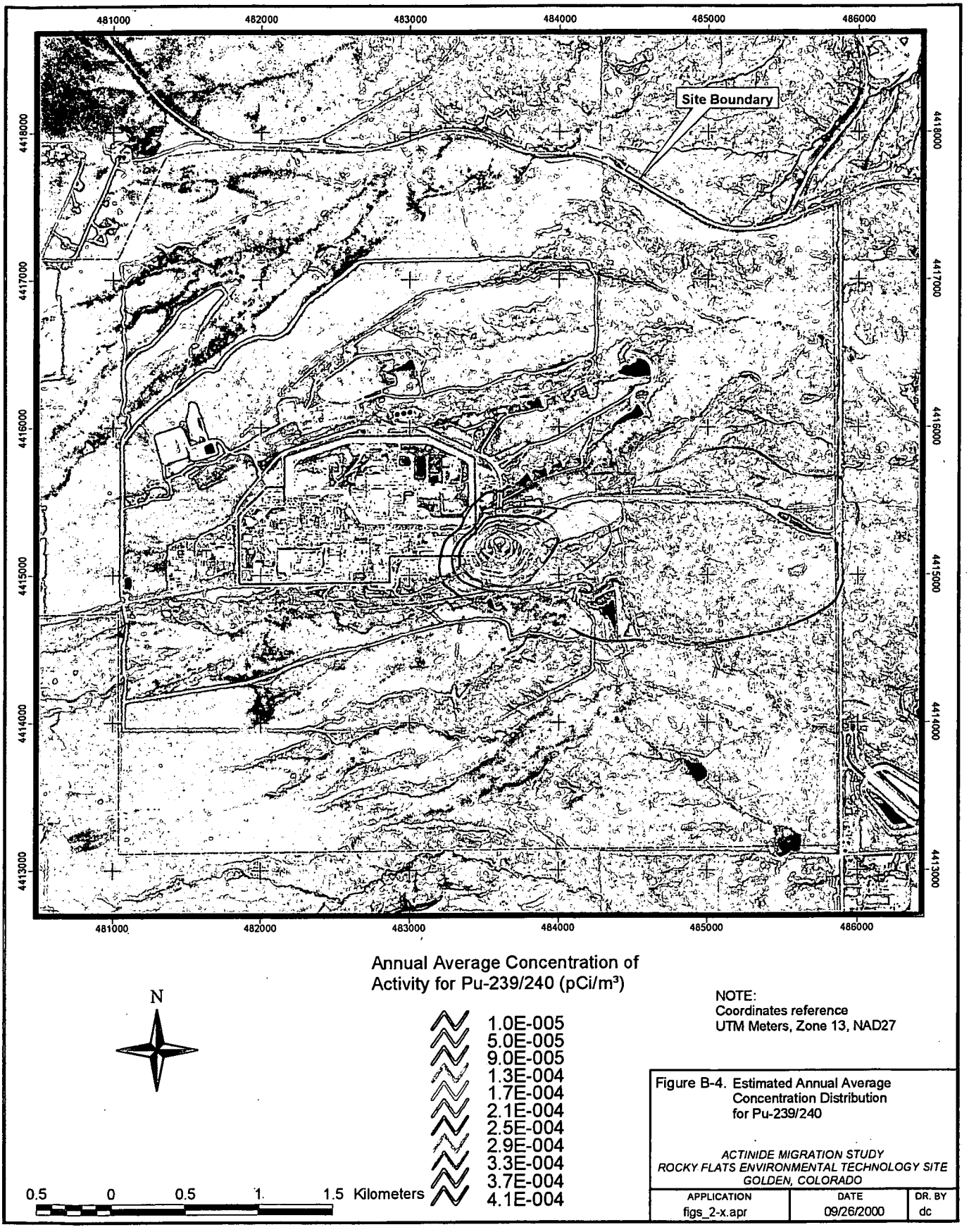

Figure B-4. Estimated Annual Average Concentration Distribution for Pu-239/240

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GOLDEN, COLORADO

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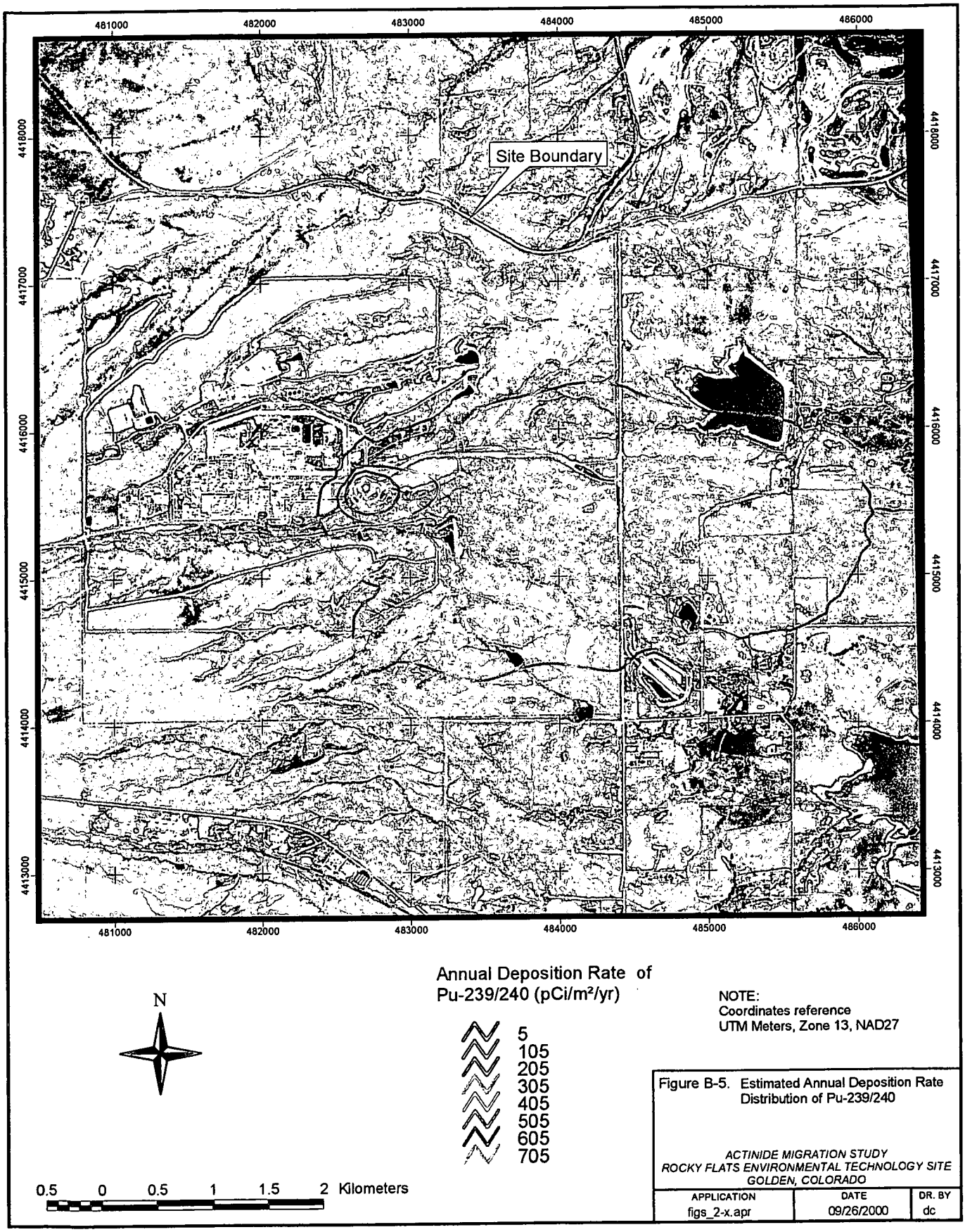

Figure B-5. Estimated Annual Deposition Rate Distribution of Pu-239/240

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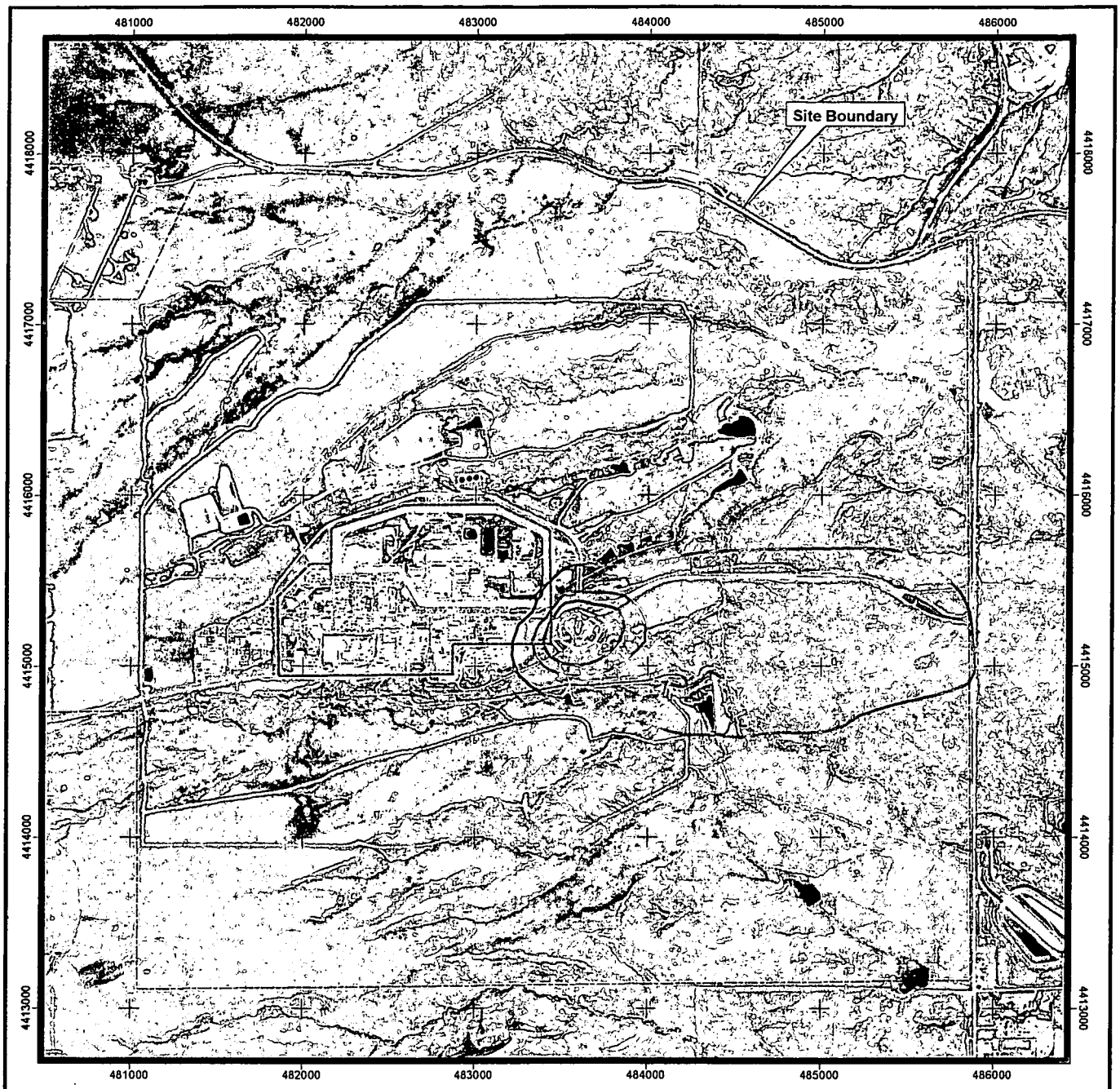

Figure B-6. Estimated Annual Average Concentration Distribution for Am-241

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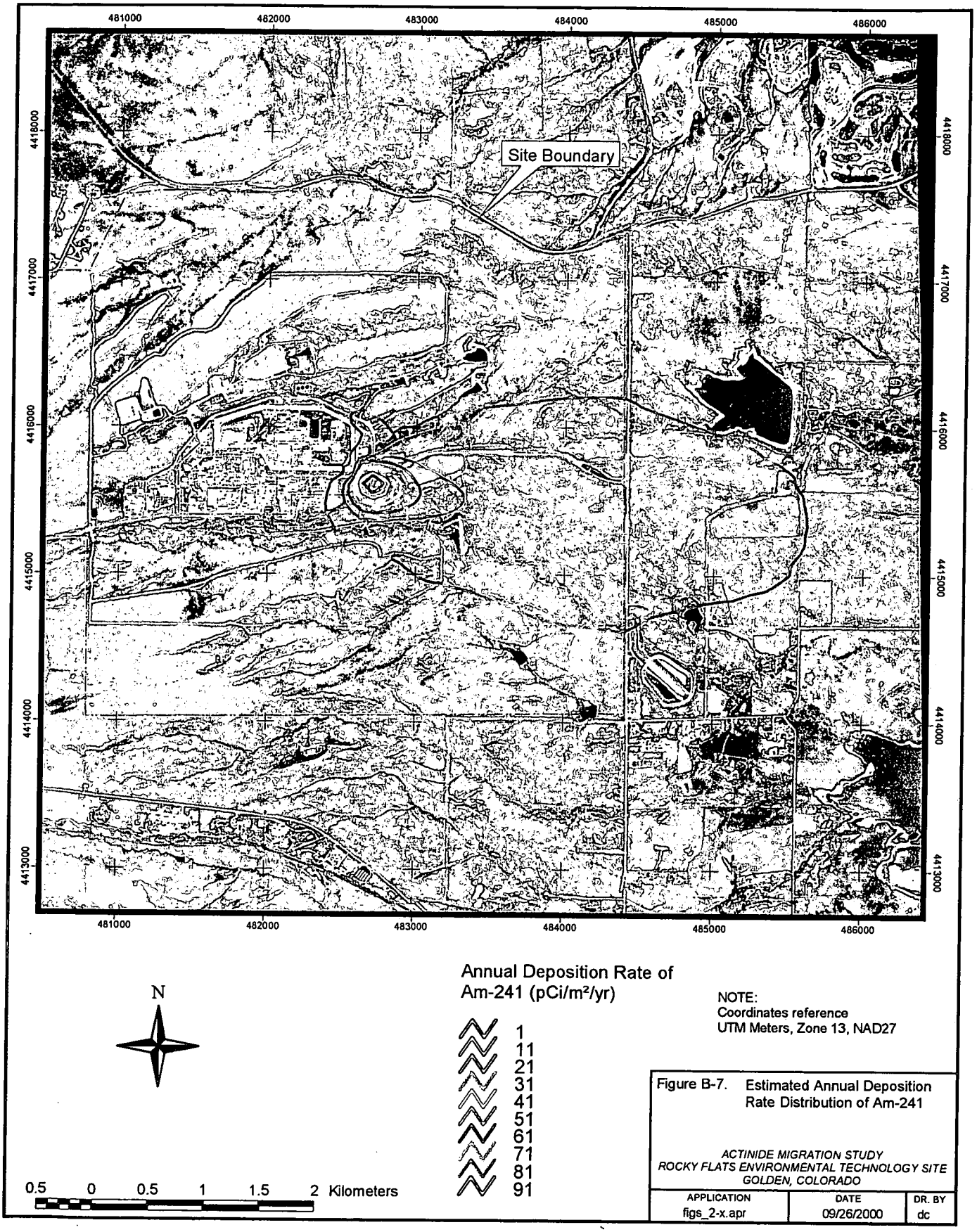

Figure B-7. Estimated Annual Deposition Rate Distribution of Am-241

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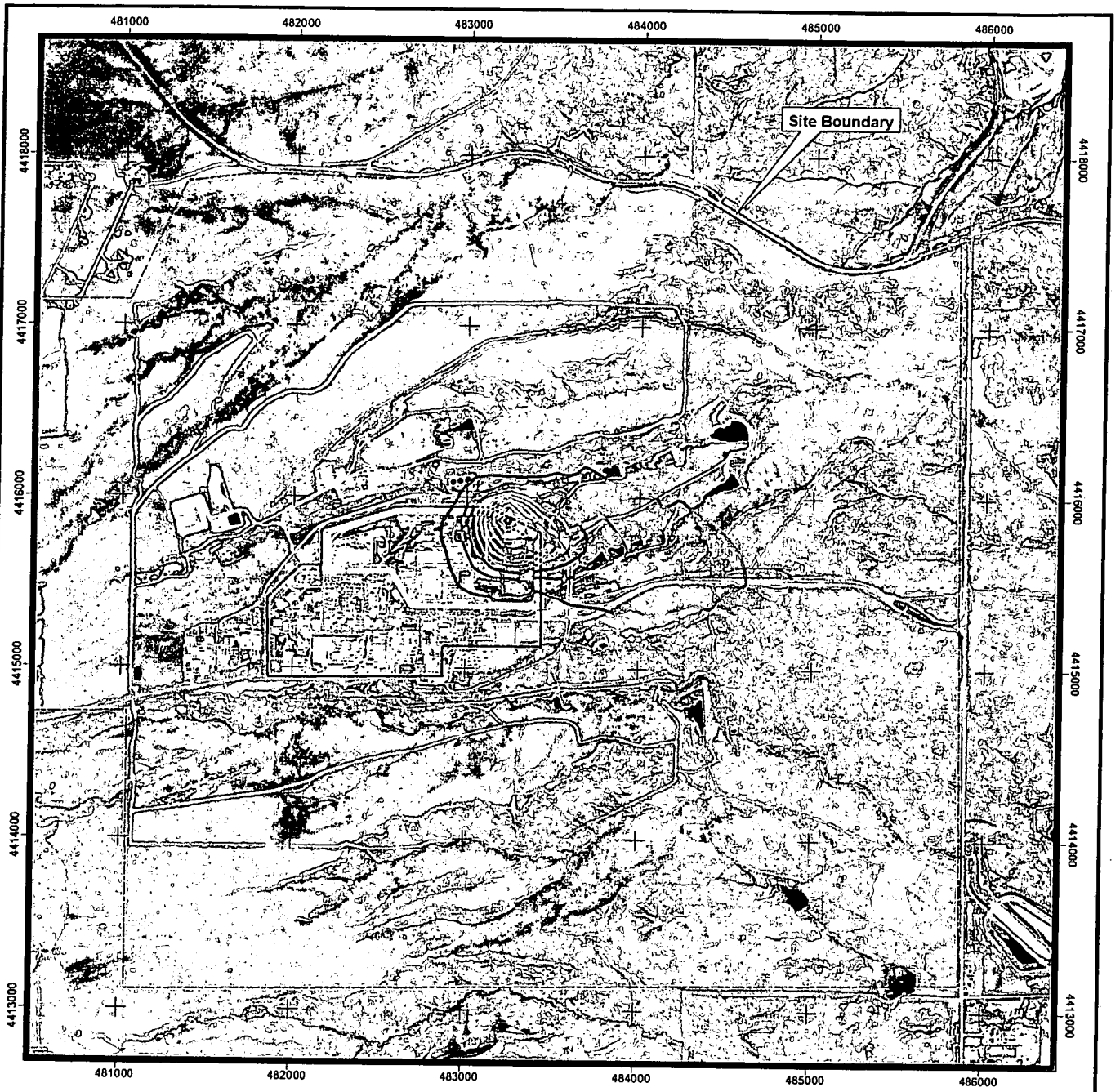

Figure B-8. Estimated Annual Average Concentration Distribution for U-233/234

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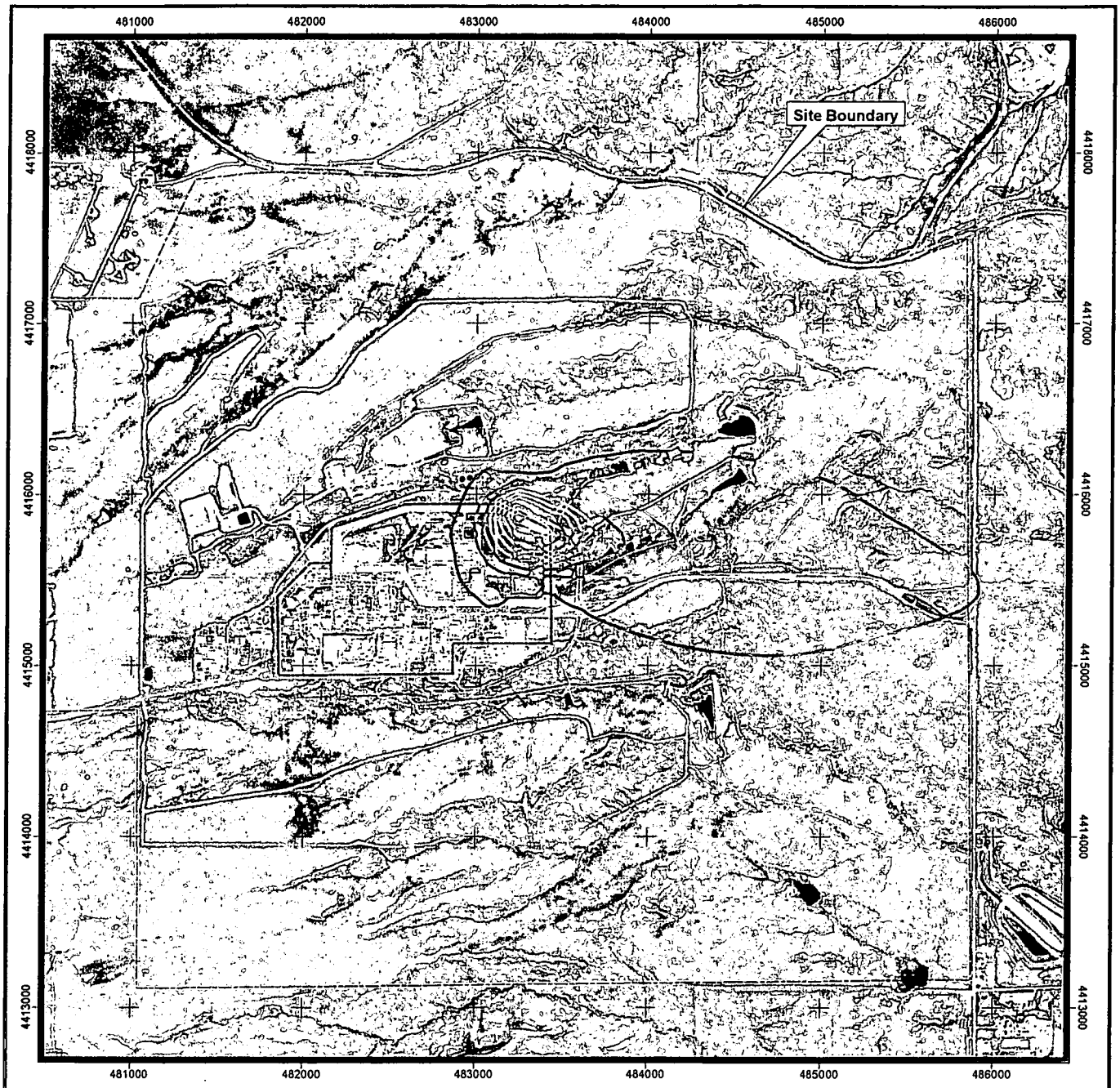

Figure B-9. Estimated Annual Deposition Rate Distribution of U-233/234

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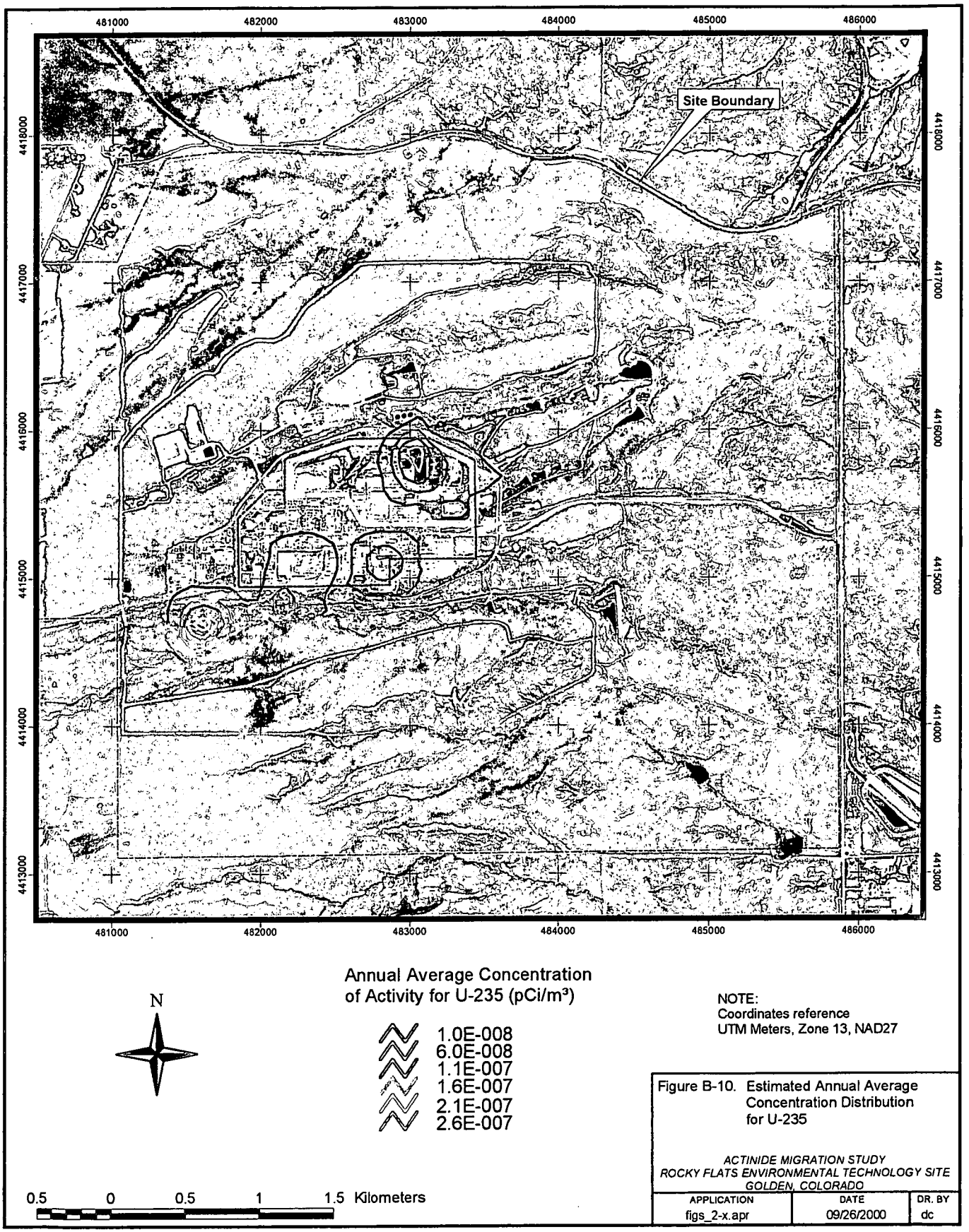

Figure B-10. Estimated Annual Average Concentration Distribution for U-235

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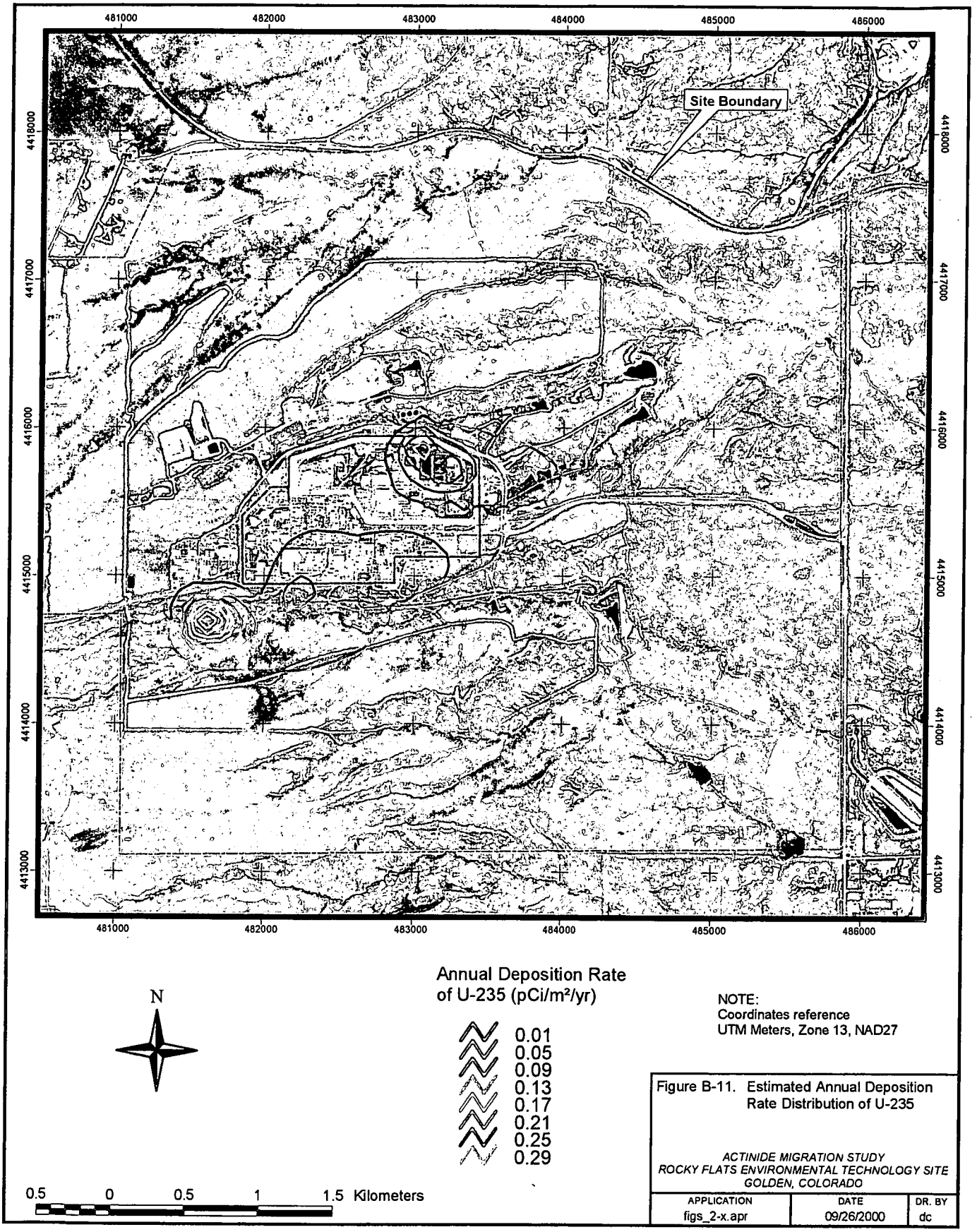

Figure B-11. Estimated Annual Deposition Rate Distribution of U-235

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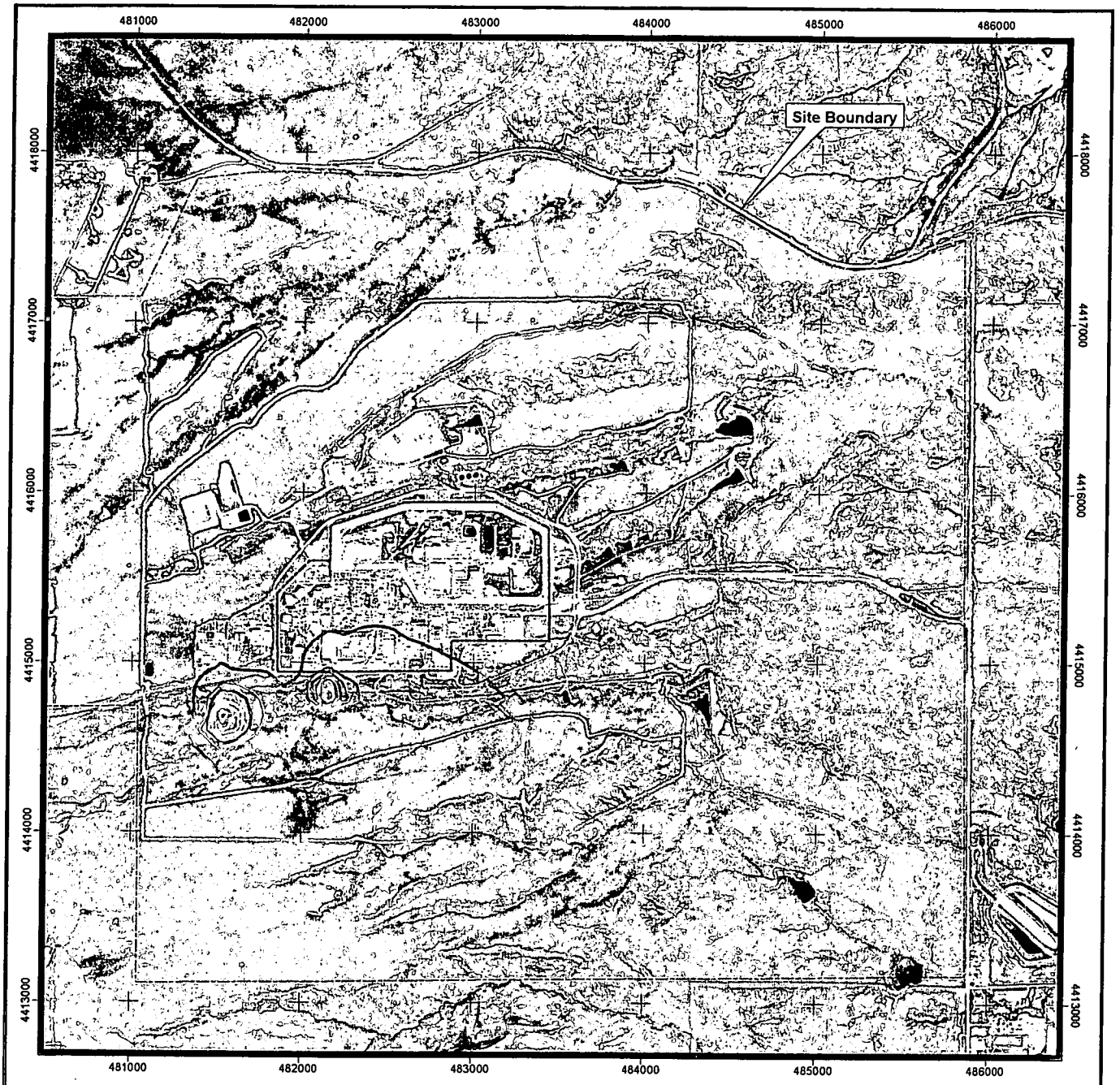

Figure B-12. Estimated Annual Average Concentration Distribution for U-238

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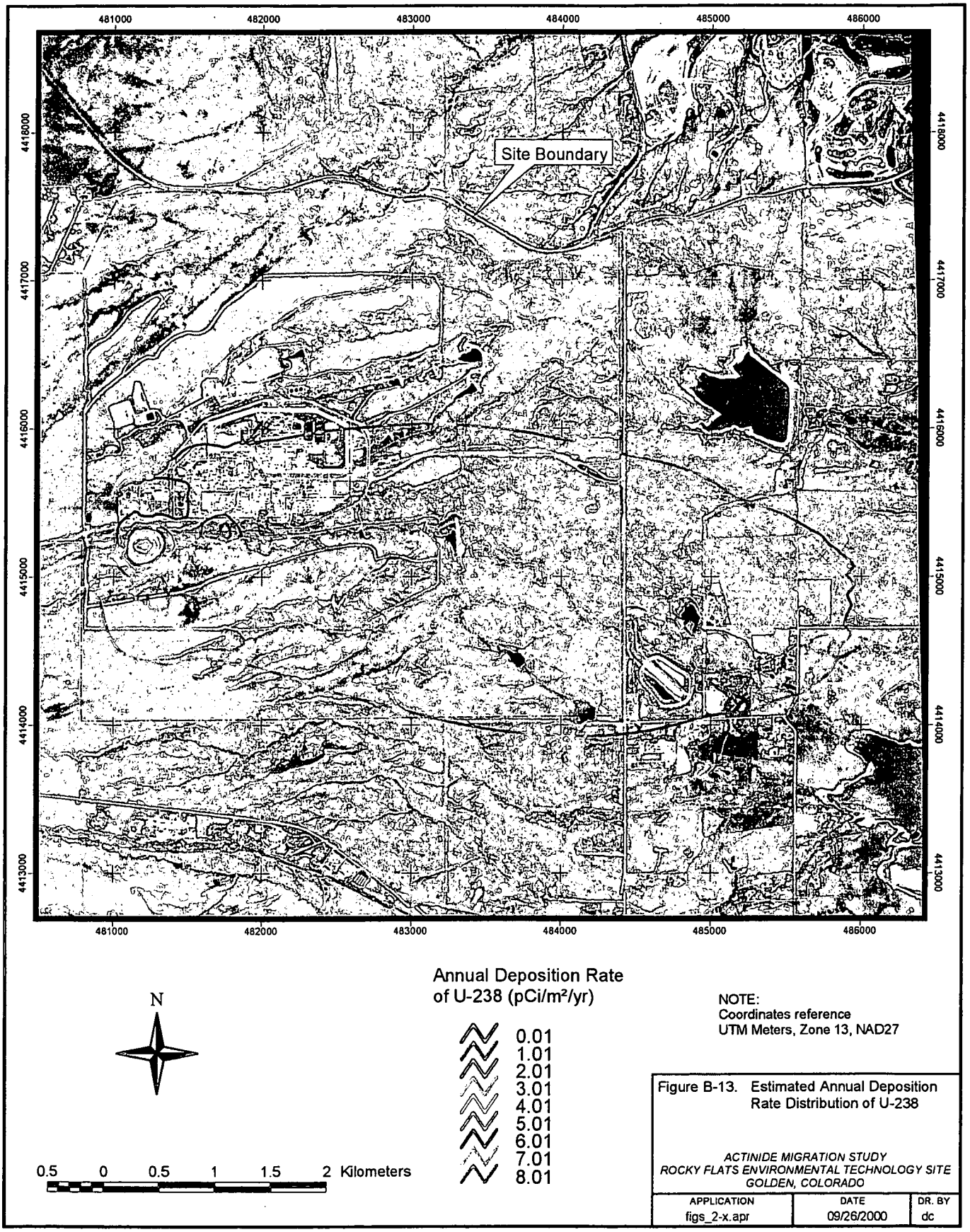

Figure B-13. Estimated Annual Deposition Rate Distribution of U-238

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Appendix C1

903 Pad Remediation Scenarios Emission Estimation

APPENDIX C1

903 PAD REMEDIATION SCENARIOS EMISSION ESTIMATION

This appendix describes the emission calculations for the annual and high wind 903 Pad remediation scenarios, described in Sections 3.1 and 3.2. All remediation activities were assumed to result in particulate emissions. Only those activities involving the excavation, handling, or transportation of contaminated soil were assumed to release actinides.

C1.1 Particulate Emission Estimation

This section discusses the equations and data used to estimate particulate emissions from the annual high wind event and remediation scenarios. Inputs specific to the Rocky Flats Environmental Technology Site (Site or RFETS) are shown in square brackets.

C1.1.1 Unpaved Roads

The empirical expression that was used to estimate the quantity in pounds (lb) of size-specific particulate emissions from an unpaved road, per vehicle mile traveled (VMT), is:

$$E = \frac{k\left(\frac{s}{12}\right)^{a}\left(\frac{W}{3}\right)^{b}}{\left(\frac{M}{0.2}\right)^{c}}$$

(AP-42, Section 13.2.2.2 [1995])

where:

k, a, b and c are empirical constants (see Table C1-1);
E is the size-specific emission factor (lb/VMT);
s is the surface material silt content (%) [15% for Site soils];
W is the mean vehicle weight (tons); and
M is the surface material moisture content (%) [10% for Site soils].

The source characteristics W, s, and M are referred to as correction parameters for adjusting the emission estimates to local conditions. The constants, based on the stated aerodynamic particle sizes, are shown in Table C1-1. The above equation was developed from tests of traffic on unpaved surfaces, either uncontrolled or watered. The ranges of source conditions that were tested in developing the equation are shown in Table C1-2. Appendices C.1 and C.2 of the U.S. Environmental Protection Agency's (EPA's) *Compilation of Air Pollutant Emission Factors, Fifth Edition* (AP-42) (EPA, 1995b) contain field and laboratory procedures for determining road surface silt and moisture content. Site soils and roadway dust have been determined to have an average silt content of 15% and an average surface moisture content of 10 percent.

Table C1-1. Constants for Unpaved Roads Equation[a]

Constant	$PM_{2.5}$	PM_{10}	PM_{30}
k	0.38	2.6	10
a	0.8	0.8	0.8
b	0.4	0.4	0.5
c	0.3	0.3	0.4

[a]Derived from AP-42, Table 13.2.2-2 (1995).

Notes:

$PM_{2.5}$ = particulate matter less than 2.5 micrometers
PM_{10} = particulate matter less than 10 micrometers
PM_{30} = particulate matter less than 30 micrometers

Table C1-2. Range of Source Conditions for Application of Unpaved Roads Equation[a]

Surface Silt Content (%)	Mean Vehicle Weight		Mean Vehicle Speed		Mean No. of Wheels	Surface Moisture Content (%)
	Mg	ton	km/hr	mph		
1.2 to 35	1.4 to 260	1.5 to 290	8 to 88	5 to 55	4 to 7	0.03 to 20

[a]Derived from AP-42, Table 13.2.2-3 (1995).

Notes:

Mg = megagrams (1,000 grams)
km/hr = kilometers per hour
mph = miles per hour

C1.1.2 Paved Roads

The empirical expression that was used to estimate the quantity of size-specific particulate emissions from a paved road is:

$$E = k\left(\frac{sL}{2}\right)^{0.65}\left(\frac{W}{3}\right)^{1.5}$$ (AP-42, Section 13.2.1.3 [1995])

where:

E is the particulate emission factor (having units matching the units of k);
k is the base emission factor for particle size range and units of interest (see Table C1-3);
sL is the road surface silt loading in grams per square meter (g/m^2) [3.38 for Site roads] (AP-42, Table 13.2.1-3 [1995]); and
W is the average weight (tons) of the vehicles traveling the road [32.4 tons for the remediation scenario].

The particle size multiplier (k) varies with aerodynamic size range, as shown in Table C1-3. As with the unpaved road equation presented previously, this equation is routinely used at the Site to estimate particulate emissions.

Table C1-3. Particle Size Multipliers for Paved Roads Equation[a]

Size Range[b]	Multiplier k[c]		
	g/VKT	g/VMT	lb/VMT
$PM_{2.5}$	1.1	1.8	0.004
PM_{10}	4.6	7.3	0.016
PM_{15}	5.5	9.0	0.020
PM_{30}	24	38	0.082

[a]Derived from AP-42, Section 13.2.1.3 (1995).
[b]Refers to airborne particulate matter (PM_x) with an aerodynamic diameter equal to or less than x micrometers.
[c]The multiplier k includes unit conversions.
Notes:
g/VKT = grams per vehicle kilometer traveled
g/VMT = grams per vehicle mile traveled
lb/VMT= pounds per vehicle mile traveled

C1.1.3 Excavation

The equation that was used for estimating total particulate matter (PM, assumed less than or equal to 30 micrometers [μm]) emissions from excavation is:

$$E = \frac{0.0046\,(d)^{1.1}}{(M)^{0.3}}$$ (AP-42, Table 11.9-2 [1995])

where:

E is the particulate emission factor (kilograms of dust per cubic meter of soil excavated, kg/m^3);
d is the drop height (meters, m)[1.52 m]; and
M is the material moisture content (%) [10% for Site soils].

C1.1.4 Contouring Backfill

The equation that was used to estimate PM emissions from bulldozer contouring operations is:

200

$$E = 5.7\left(\frac{(s)^{1.2}}{(M)^{1.3}}\right)$$ (AP-42, Table 11.9-1 [1995])

where:

E is the particulate emission rate in pounds per hour (lb/hr);
s is the percentage silt (%) [15% for Site soils]; and
M is the material moisture content (%) [10% for Site soils].

The equation used to estimate fine particulate matter (PM_{10}) emissions from these operations was:

$$E = 0.75\left(\frac{(s)^{1.5}}{(M)^{1.4}}\right)$$ (AP-42, Table 11.9-1 [1995])

where:

E is the PM_{10} emission rate (lb/hr);
s is the percentage silt (%) [15% for Site soils]; and
M is the material moisture content (%) [10% for Site soils].

C1.1.5 Storage Pile Loading and Front-End Loader Material Handling

Dust emissions from storage piles and material handling occur at several points in the storage cycle, such as material loading onto the pile, disturbances by strong winds, and loadout from the pile. The quantity of dust emissions from soil storage operations varies with the volume of soil passing through the storage cycle. Emissions also depend on three parameters that describe the condition of a particular storage pile: age of the pile, moisture content, and proportion of fines.

When soil is loaded onto a storage pile, the potential for dust emissions is at a maximum. Fines are easily separated and released to the atmosphere upon exposure to air currents, either from stored material transfer itself or from high winds. As the storage pile weathers, however, the potential for dust emissions is greatly reduced. Moisture causes aggregation and cementation of fines to the surfaces of larger particles. Any significant rainfall soaks the interior of the pile, and the drying process is then very slow. Adding or removing material to/from a storage pile usually involves dropping the material onto a receiving surface. Truck and front-end loader dumping on the pile or loading out from the pile to a truck or crate with a front-end loader are the typical batch drop operations associated with this remediation scenario.

The quantity of particulate emissions generated by drop operations, per kilogram (kg) of material transferred, may be estimated using the following empirical expression:

$$E = k \frac{(0.0016)\left(\frac{U}{2.2}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}}$$

(AP-42, Section 13.2.4.3 [1995])

where:

E is the emission factor (kg/megagram [Mg]);
k is the particle size multiplier (dimensionless);
U is the mean wind speed, meters per second (m/s); and
M is the material moisture content (%) [10% for Site soils].

The particle size multiplier in the equation, k, varies with aerodynamic particle size range, as shown in Table C1-4. The factor for <50 μm is 1.0.

Table C1-4. Particle Size Multipliers For Storage Pile Loading Equation[a]

Aerodynamic Particle Size Multiplier (k) For Storage Pile Equation				
<30 μm	<15	<10 μm	<5 μm	<2.5 μm
0.74	0.48	0.35	0.20	0.11

[a]Derived from AP-42, Section 13.2.4.3 (1995).
Note:
μm = micrometer

C1.1.6 Wind Erosion of Conical Storage Pile Surfaces and Exposed Ground

Surface soils and storage piles do not have unlimited reservoirs of particulate erosion potential because of pile weathering. When surface weathering is taken into consideration, particulate emissions (expressed as erosion potential) become a function of wind speed and frequency of pile surface disturbances. Each surface disturbance renews the available reservoir of erodible material.

When determining limited-reservoir erosion potential of exposed soil surfaces and storage piles, the fastest mile wind speed is used to account for the magnitude of wind gusts. The fastest mile wind speed is defined as the wind speed that corresponds to the whole mile of wind movement that has passed by the 1 mile contact anemometer in the least amount of time. This value is estimated as:

$U+^{10} = (1.4)(U)$ (Cowherd, 2000)

where:

U^{+10} is the fastest-mile wind speed at 10 m height (m/s); and
U is the mean wind speed (m/s).

Using the fastest-mile wind speed for any given period, the friction velocity of wind impacting a horizontal soil surface was calculated using the following equation:

$u^* = (0.053)(U^{+10})$ (AP-42, Section 13.2.5.3 [1995])

where:

u^* is the friction velocity (m/s);
U^{+10} is the fastest-mile wind speed at 10 m height (m/s); and
0.053 is a logarithmic conversion factor for converting wind speed at 10 m to groundlevel friction velocity, assuming a surface roughness height of 0.5 centimeters (cm).

The threshold friction velocity (u_t) for surface soil and overburden was assumed to be 1.02 m/s, based on AP-42, Table 13.2.5-2 (1995). When $u^* > u_t$, erosion potential exists for the soil surface in question. The erosion potential for any horizontal soil surface on which the wind friction velocity exceeds the threshold velocity may be estimated as:

$P = 58(u^* - u_t)^2 + 25(u^* - u_t)$ (AP-42, Section 13.2.5.3 [1995])

where:

P is the erosion potential (g/m^2);
u^* is the friction velocity (m/s);
u_t is the threshold friction velocity (m/s);
58 is an empirical constant (unitless); and
25 is an empirical constant (unitless).

The erosion potential is renewed with each surface disturbance. For this model, 10 disturbances a day were assumed for each day in which remediation work would occur. Because of the shallow depth of each cell strip's excavation, all surfaces were treated as horizontal for purposes of estimating erosion potential.

Unlike horizontal soil surfaces, storage piles offer an infinite set of surface impact angles to the wind. To account for the differing impact angles of wind on a conical storage pile's surfaces compared to horizontal ground, the pile was subdivided into four sections

in accordance with AP-42, Section 13.2.5.3 (1995). The friction velocity for each surface section becomes:

$u^* = (0.10)(U^{+10})(s)$ (AP-42, Section 13.2.5.3 [1995])

where:

u^* is the friction velocity (m/s);
0.10 is an empirical constant (unitless);
U^{+10} is the fastest mile wind speed at 10 m height (m/s); and
s is the unitless surface section correction factor (see Table C1-5).

Table C1-5. Subarea Distribution for Conical Storage Piles[a]

Pile Subarea	Surface Section Correction Factor (s)	Percent of Pile Surface Area
0.2a	0.2	5
0.2b	0.2	35
0.6a	0.6	48
0.9	0.9	12

[a]Derived from AP-42, Table 13.2.5-3 (1995).

The threshold friction velocity (u_t) of piled soils was assumed to be 1.02 m/s, based on AP-42, Table 13.2.5-2 (1995). As with horizontal surfaces, when $u^* > u_t$, erosion potential exists for the surface in question. The erosion potential equation for each pile surface was the same as for horizontal surfaces, since the difference in wind impact angle has already been addressed in calculating the friction velocity:

$P = 58(u^* - u_t)^2 + 25(u^* - u_t)$ (AP-42, Section 13.2.5.3 [1995])

where:

P is the erosion potential (g/m^2);
u^* is the friction velocity (m/s);
u_t is the threshold friction velocity (m/s);
58 is an empirical constant (unitless); and
25 is an empirical constant (unitless).

The erosion potential is renewed with each pile disturbance. For this model, 10 disturbances a day were assumed for each day in which remediation work would occur.

The particle size multipliers for particulate emissions from storage piles and exposed soils are presented in Table C1-6:

Table C1-6. Particle Size Multipliers for Storage Pile and Surface Erosion by Wind[a]

Particle Size			
<30 μm	<15 μm	<10 μm	<2.5 μm
1.0	0.6	0.5	0.2

[a]Derived from AP-42, Section 13.2.5.3 (1995).
Note:
μm = micrometer

C1.2 Actinide Release Estimation

The empirical expression used to estimate the radioactivity released, in picocuries (pCi), from each radioisotope associated with the particulate emissions in grams (g) from each remediation activity is:

$R = E_r \times A$

where:

R is the radioactivity released as that isotope, in picocuries per square meter per second ($pCi/m^2/s$);
E_r is the PM emission rate in grams per square meter per second ($g/m^2/s$) for each remediation activity; and
A is the average soil concentration of that isotope within the cell strip, in picocuries per gram (pCi/g).

The value R represents, for each isotope, the total radioactivity that was attached to the soil-derived particulate emissions. The actual airborne activity was refined in the model because of particle-size partitioning, gravitational settling, and other mechanisms that reduce the available radioactivity from its maximum potential. This process is discussed in more detail in Section 3.1.3 of this report.

The soil actinide concentrations that were averaged to determine A for each cell strip were obtained from 903 Pad remediation project staff and appear in Table C1-7 (Paris, 2000).

Table C1-7. Isotopic Concentrations from Soil Borehole Data, 903 Pad Remediation Area

Cell Strip	Volume (yd^3)	Interval (ft)	U-233/234 (pCi/g)	U-235 (pCi/g)	U-238 (pCi/g)	Pu-239/240 (pCi/g)	Am-241 (pCi/g)
903 Pad Radiological Boreholes							
1	105	1.4-1.9	0.75	0.09	1.23	2,500.00	377.00
1	105	1.5-2.0	19.80	7.20	28.20	152,260.00	31,670.00
1	105	2.0-2.5	0.98	0.14	1.12	167.00	33.20
Average Activity:			**7.18**	**2.48**	**10.18**	**51,642.33**	**10,693.40**
2	105	0.8-1.5	5.14	0.58	7.92	10,670.00	1,880.00
2	105	0.9-1.4	1.83	-0.91	0.91	389.00	3,930.00
Average Activity:			**3.49**	**-0.17**	**4.42**	**5,529.50**	**2,905.00**
3	105	0.8-1.1	3.11	0.21	8.50	9,110.00	1,510.00
3	105	1.1-1.6	0.84	0.05	1.72	7,960.00	535.00
Average Activity:			**1.97**	**0.13**	**5.11**	**8,535.00**	**1,022.50**
4	105	0.9-1.4	3.56	0.17	5.21	685.00	158.00
4	105	0.8-1.3	178.00	16.90	780.00	6,600.00	1,210.00
4	105	0.6-1.1	2.02	0.49	2.77	558.00	126.00
4	105	1.1-1.6	10.70	2.52	13.20	2,420.00	554.00
4	105	1.3-1.8	0.44	0.07	0.72	201.00	10.30
4	105	1.6-2.1	1.65	0.38	1.38	212.00	29.20
Average Activity:			**32.73**	**3.42**	**133.88**	**1,779.33**	**347.92**
5,6	140	0.8-1.3	6.18	1.74	15.20	768.00	146.00
5,6	140	0.8-1.3	10.80	0.57	26.80	1,210.00	268.00
5,6	140	0.9-1.4	2.53	0.96	2.69	581.00	116.00
5,6	140	1.4-1.9	11.40	6.57	8.51	1,480.00	256.00
Average Activity:			**7.73**	**2.46**	**13.30**	**1,009.75**	**196.50**
Lip Area Radiological Boreholes							
7	140	0.45-0.9	1.20	0.05	2.97	669.00	170.00
7	140	0.9-1.35	0.83	0.06	1.76	156.00	29.50
Average Activity:			**1.01**	**0.06**	**2.37**	**412.50**	**99.75**
8,11	140	0.0-0.5	1.29	-0.20	2.53	808.00	128.00
8	140	0.0-0.5	1.13	0.09	3.78	1,170.00	225.00
Average Activity:			**1.21**	**-0.06**	**3.16**	**989.00**	**176.50**
9,10	140	0.0-0.4	35.80	4.17	75.70	14,950.00	3,140.00
9,10	140	0.0-0.4	0.80	0.06	1.32	362.00	80.80
9,10	140	0.4-0.8	1.07	0.07	2.30	785.00	209.00
9,10	140	0.8-1.2	1.48	0.12	3.12	247.00	54.40
9,10,12	140	0.0-0.5	3.28	0.12	8.66	3,300.00	880.00
9,10,12	140	0.5-1.0	2.05	0.15	6.79	1,820.00	406.00
9,10,12	140	1.0-1.5	1.29	0.14	2.71	115.00	25.80
Average Activity:			**6.54**	**0.69**	**14.37**	**3,082.71**	**685.14**
8,11	140	0.0-0.5	1.29	-0.20	2.53	808.00	128.00
11	140	0.0-0.5	1.14	0.06	2.74	858.00	176.00
11	140	0.5-1.0	0.91	0.03	1.24	412.00	89.50
Average Activity:			**1.11**	**-0.04**	**2.17**	**692.67**	**131.17**

Table C1-7. (Continued)

9,10,12	140	0.0-0.5	3.28	0.12	8.66	3300.00	880.00
9,10,12	140	0.5-1.0	2.05	0.15	6.79	1820.00	406.00
9,10,12	140	1.0-1.5	1.29	0.14	2.71	115.00	25.80
12	140	0.0-0.5	1.94	0.19	6.34	978.00	182.00
12	140	0.5-1.0	1.63	0.09	5.07	683.00	136.00
Average Activity:			**2.04**	**0.14**	**5.91**	**1379.20**	**325.96**
HPGE Radiological Data							
Am Zone	6	0-0.5	4.27	0.22	4.27	680.39	149.11
Am Zone	6	0-0.5	4.20	0.22	4.20	541.45	119.24
Am Zone	6	0-0.5	4.83	0.25	4.83	641.43	140.73
Lip Area	6	0-0.5	4.97	0.27	4.97	566.07	124.53
Average Activity:			**4.57**	**0.24**	**4.57**	**607.33**	**133.40**

Notes:

Am = amercium
ft = foot
HPGE = high purity gemanium (gamma detection method)
pCi/g = picocuries per gram
Pu = plutonium
U = uranium
yd^3 = cubic yard

C1.3 High Wind Event

As described in Section 3.2.2, particulate and actinide emissions were also estimated for a 24-hour high wind event during remediation of the 903 Pad. Certain emissions were based on meteorological parameters measured at the Site during 19 April 1996. That day had the highest average wind speeds of any day for which complete data were available over a four-year period. The meteorological data for 19 April 1996 are shown in Table C1-8.

Table C1-8. 19 April 1996 Meteorological Data

Hour of Day	Temperature (°C)	Wind Speed (m/s)	Direction (degrees)[a]	Fastest Mile Wind Speed (m/s)
1	2.8	17.3	280.9	24.2
2	2.5	16.0	281.3	22.4
3	1.3	13.0	272.4	18.2
4	1.6	19.3	262.8	27.0
5	1.1	20.1	273.4	28.2
6	0.6	19.7	271.3	27.6
7	1.1	22.3	281.7	31.2
8	1.7	19.6	281.0	27.5
9	2.9	20.6	275.9	28.8
10	3.1	22.0	274.3	30.8
11	3.5	19.2	279.2	26.9
12	4.7	15.9	295.2	22.3
13	5.6	12.4	289.2	17.4
14	6.0	11.7	297.7	16.3
15	6.9	11.5	284.2	16.1
16	6.2	11.9	286.8	16.6
17	5.7	12.5	280.6	17.6
18	5.5	10.5	273.3	14.7
19	4.7	11.4	277.6	15.9
20	4.1	11.6	286.0	16.3
21	4.2	13.4	282.4	18.7
22	3.8	12.5	279.4	17.5
23	3.6	11.5	280.4	16.0
24	4.0	10.9	291.3	15.3
			m/s	**mph**
Mean Wind Speed:			**15.3**	**34.2**
Maximum Wind Speed:			**22.3**	**49.8**
Minimum Wind Speed:			**10.5**	**23.6**

[a]Direction wind is blowing from.

Notes:

°C = degrees Celsius

m/s = meters per second

mph = miles per hour

Appendix C2

903 Pad Remediation Scenarios Modeling Results

APPENDIX C2

903 PAD REMEDIATION SCENARIOS MODELING RESULTS

This appendix presents the results of the modeling for the two 903 Pad remediation scenarios. The results are discussed in Sections 3.1.4 and 3.2.4. The modeling for the high wind event used meteorological data for 19 April 1996, shown in Appendix C1, Table C1-9.

Figures C2-1 through C2-12 show the results of the annual remediation scenario. Figures C2-13 through C2-17 show the results for the simulated high wind event.

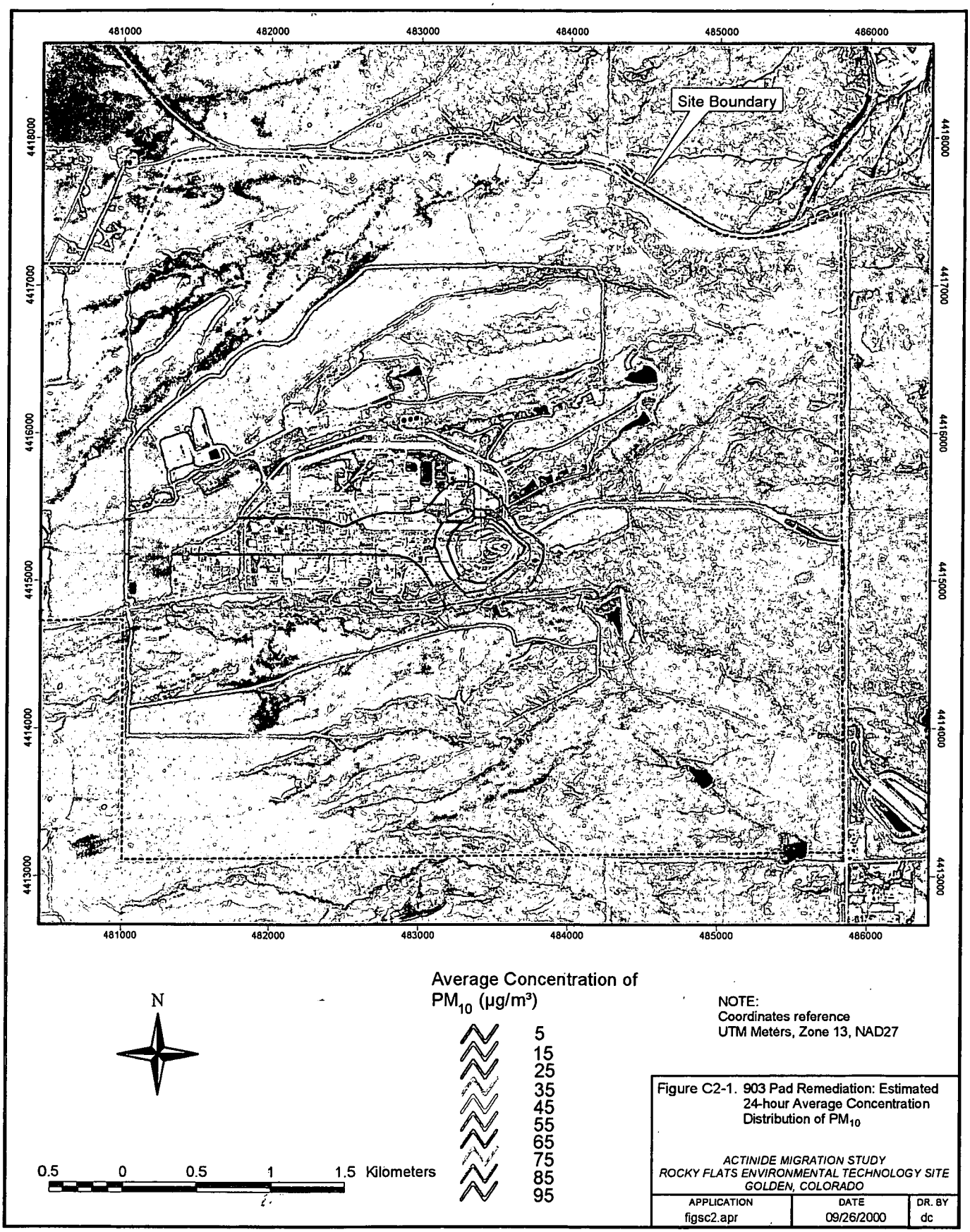

Figure C2-1. 903 Pad Remediation: Estimated 24-hour Average Concentration Distribution of PM_{10}

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ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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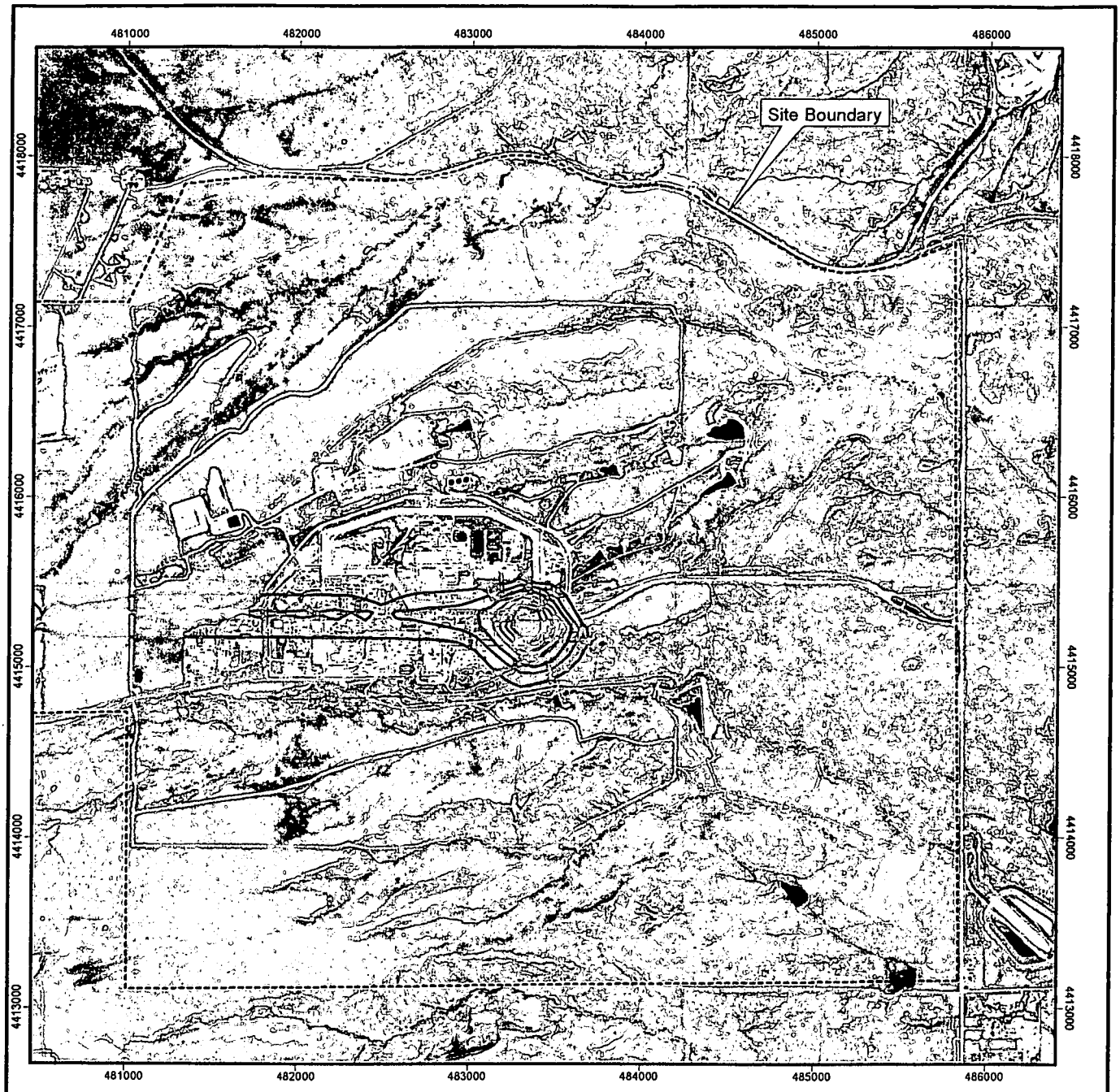

Figure C2-2. 903 Pad Remediation: Estimated Annual Average Concentration Distribution of PM_{10}

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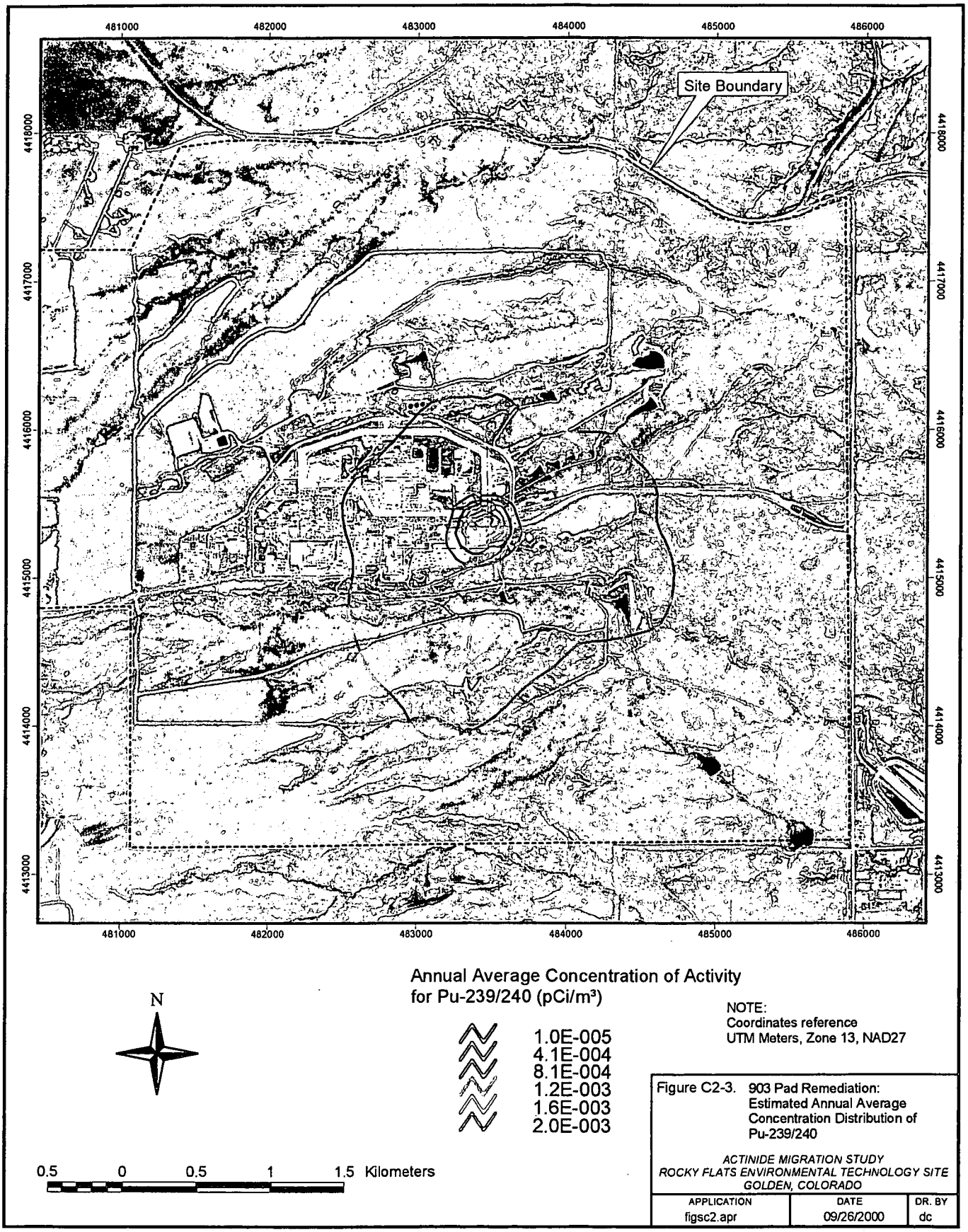

Figure C2-3. 903 Pad Remediation: Estimated Annual Average Concentration Distribution of Pu-239/240

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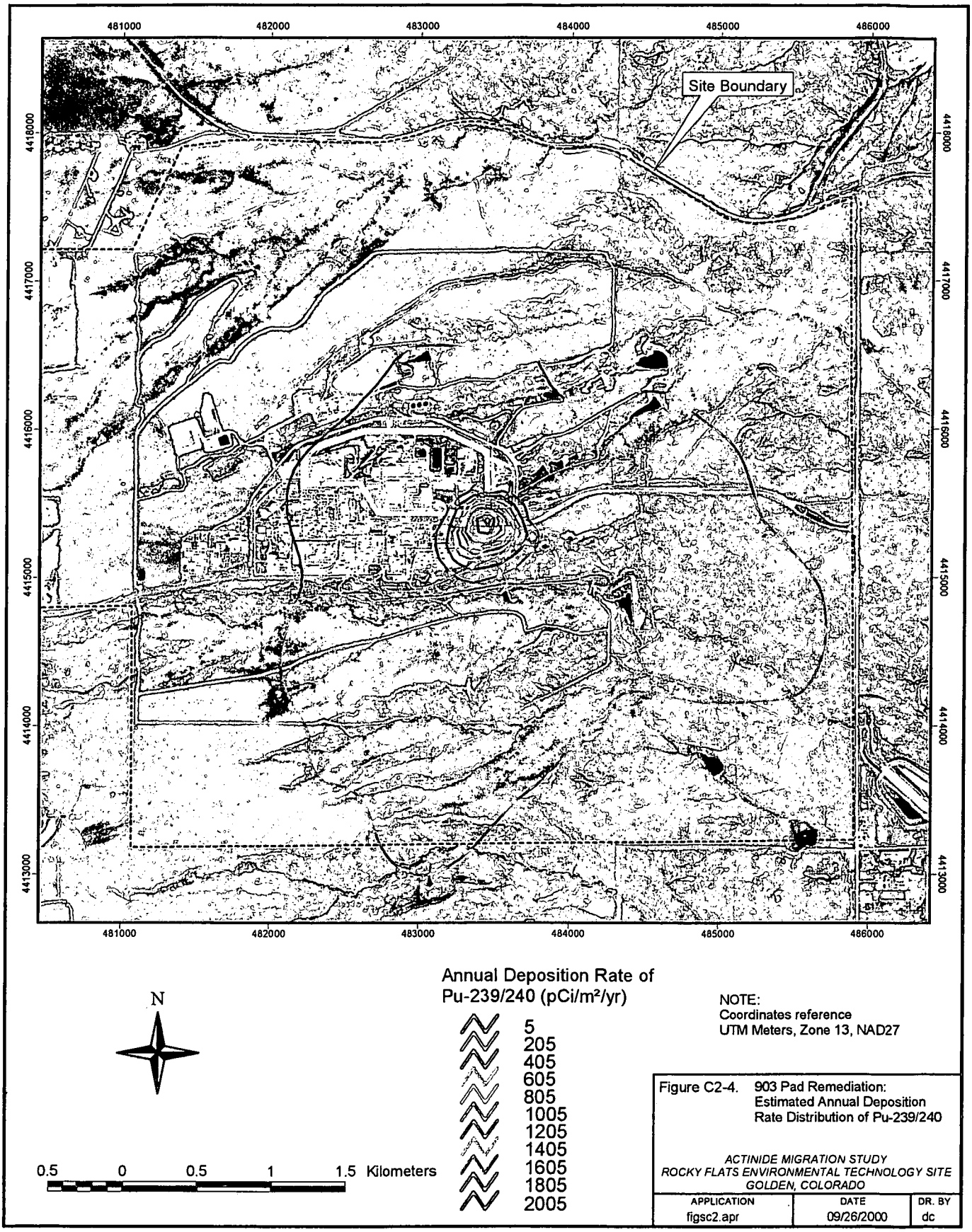

Figure C2-4. 903 Pad Remediation: Estimated Annual Deposition Rate Distribution of Pu-239/240

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ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
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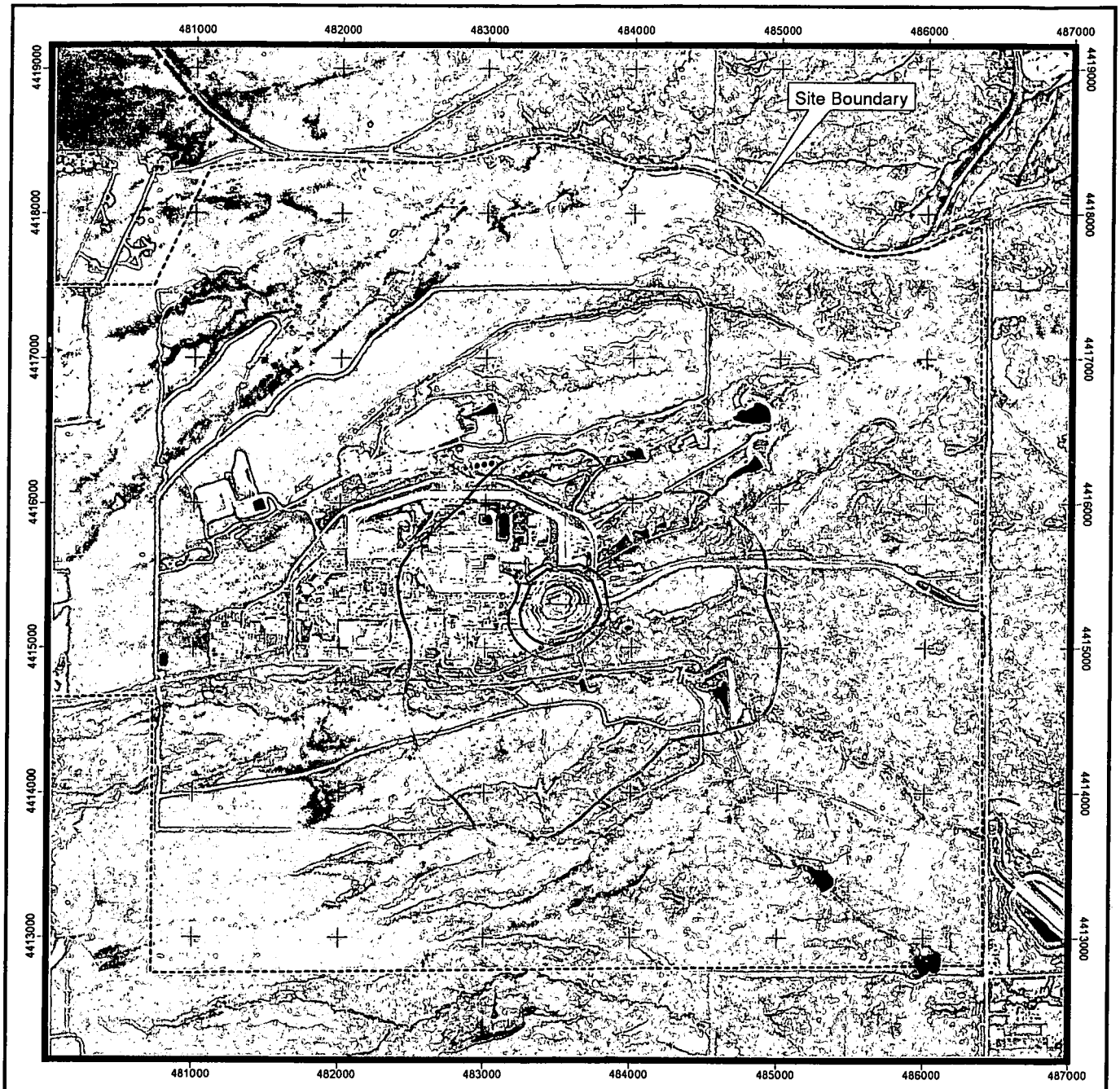

Annual Average Concentration of Activity for Am-241 (pCi/m³)

2.0E-006
1.0E-004
1.5E-004
2.0E-004
2.5E-004
3.0E-004
3.5E-004
4.0E-004
4.5E-004

N

0.5 0 0.5 1 1.5 Kilometers

NOTE:
Coordinates reference
UTM Meters, Zone 13, NAD27

Figure C2-5. 903 Pad Remediation: Estimated Annual Average Concentration Distribution of Am-241

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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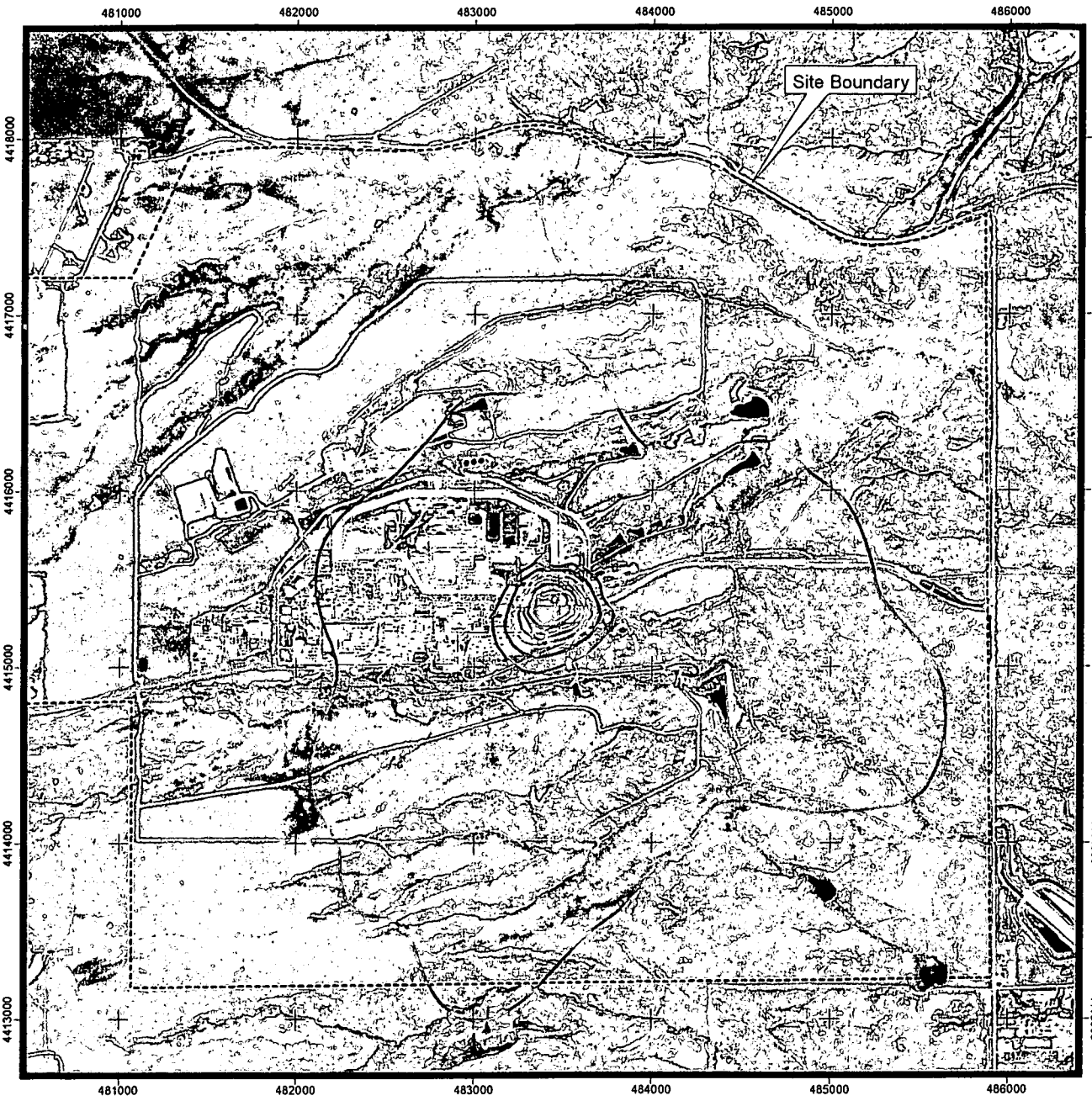

Figure C2-6. 903 Pad Remediation: Estimated Annual Deposition Rate Distribution of Am-241

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ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
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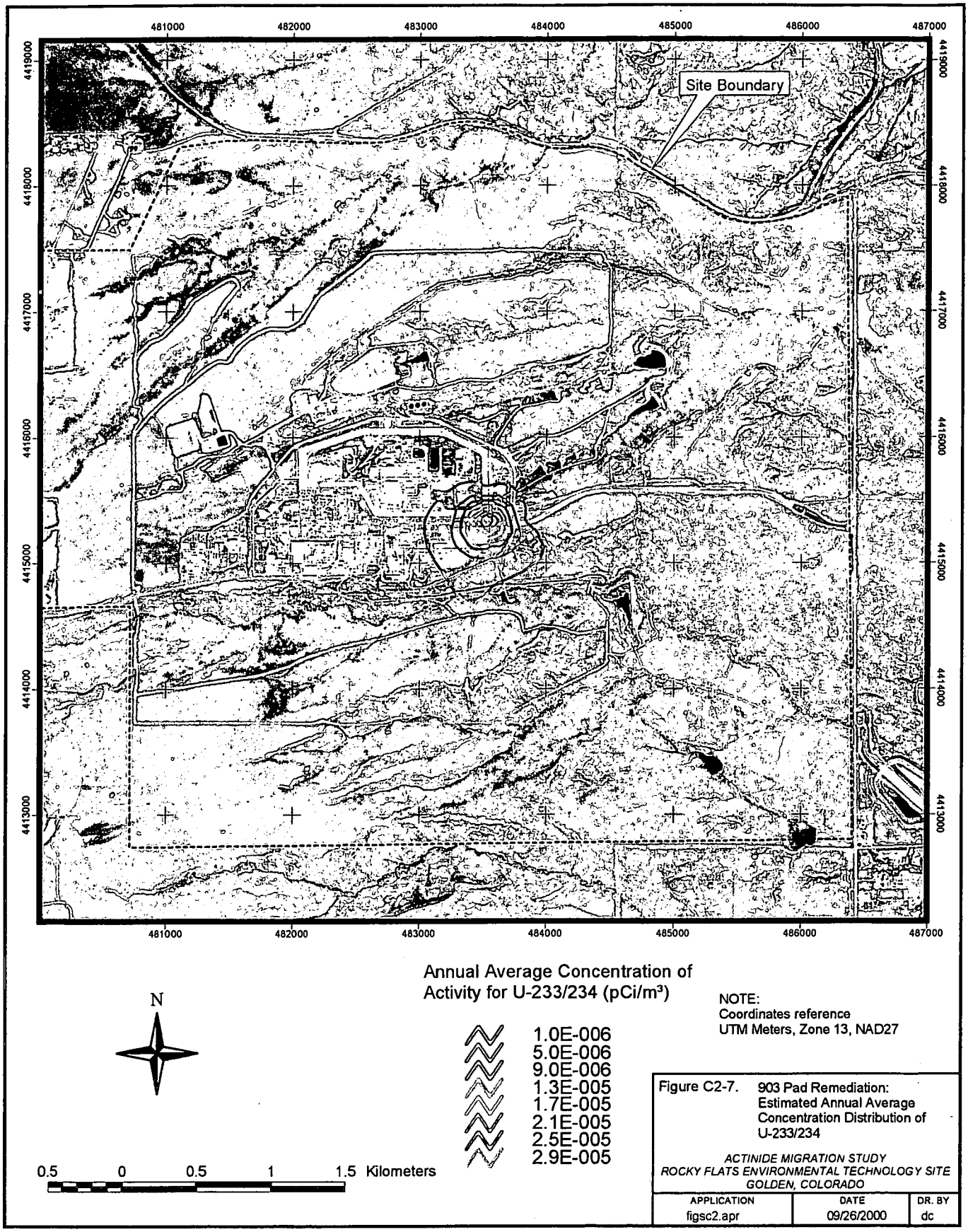

Figure C2-7. 903 Pad Remediation: Estimated Annual Average Concentration Distribution of U-233/234

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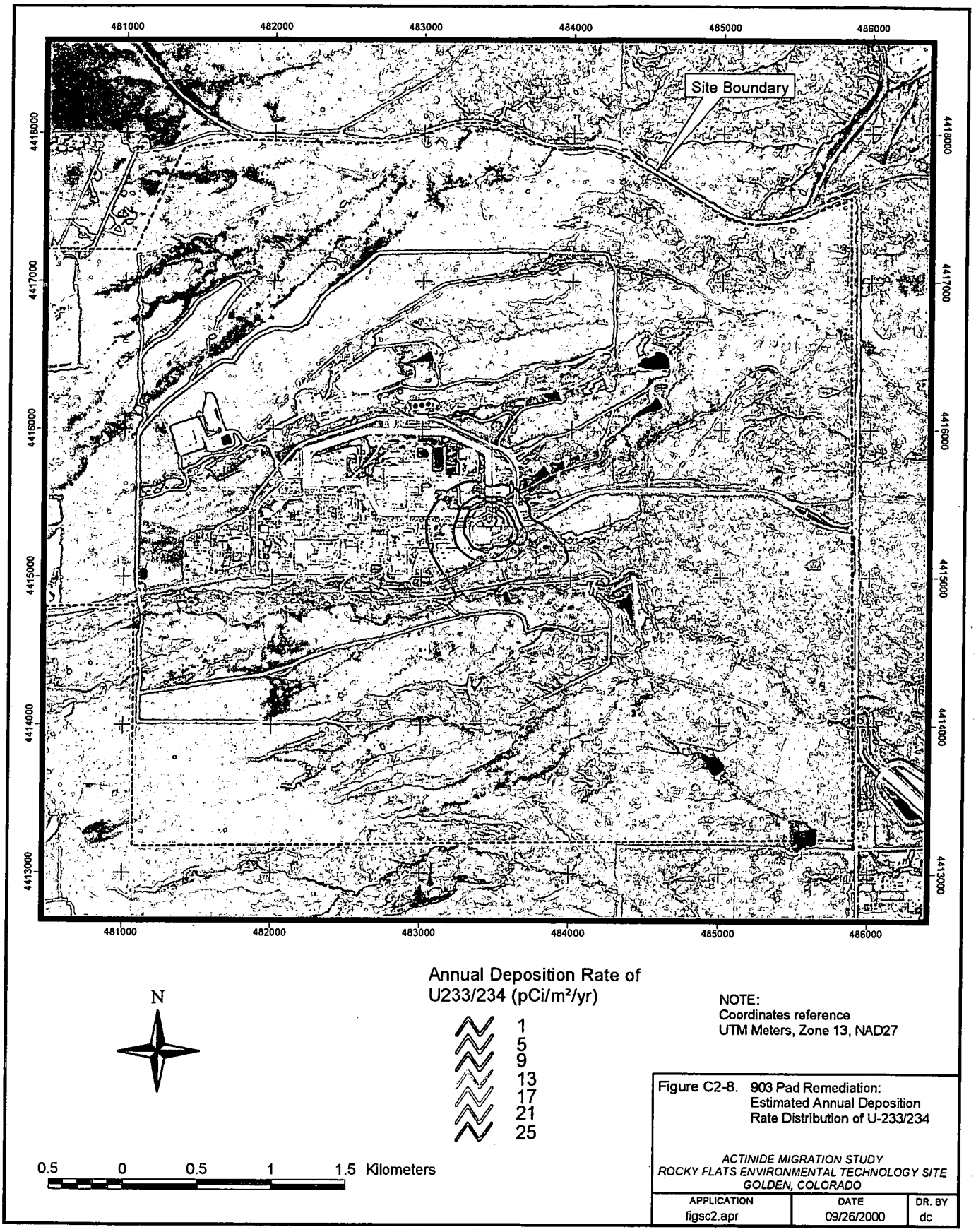

Figure C2-8. 903 Pad Remediation: Estimated Annual Deposition Rate Distribution of U-233/234

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ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
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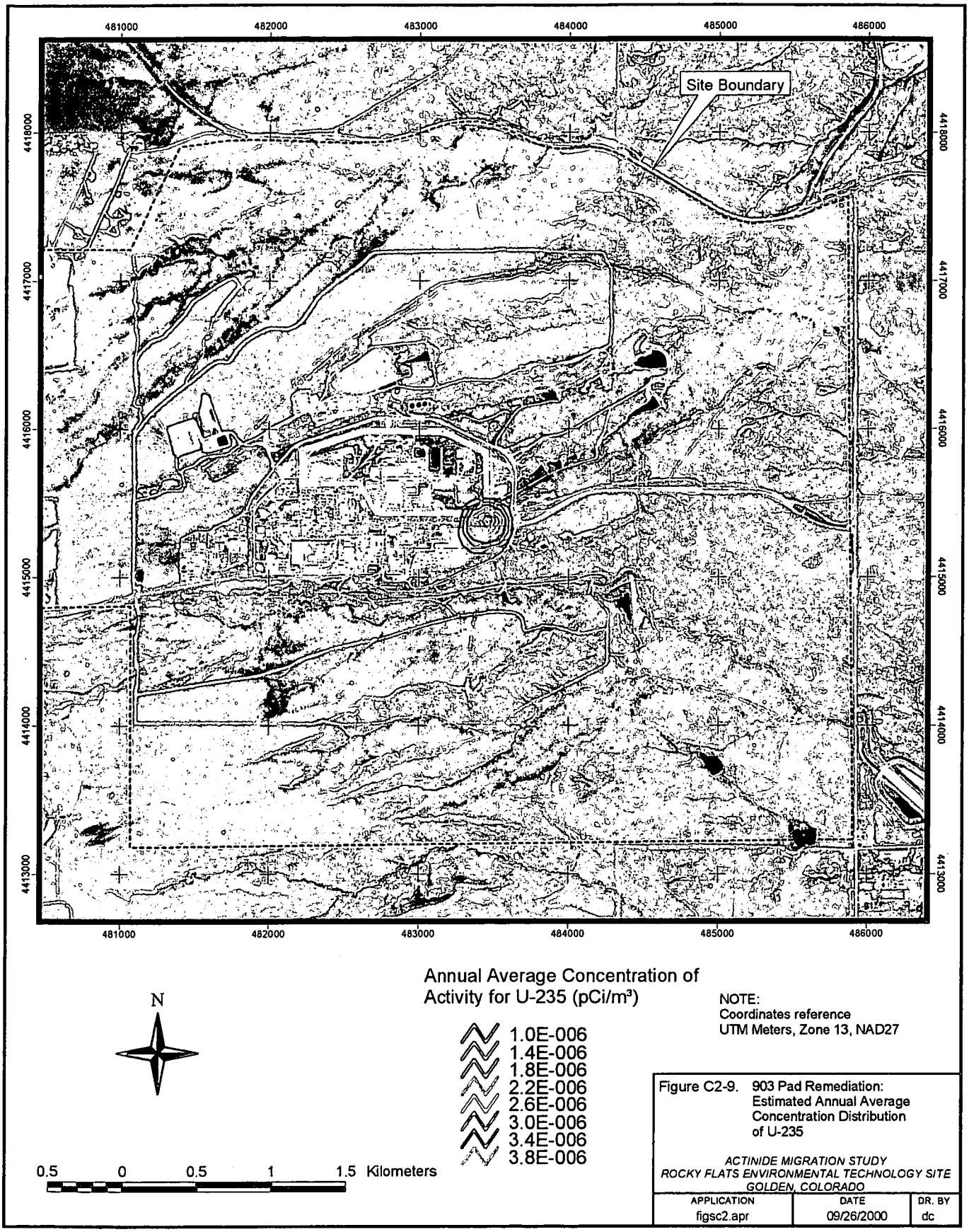

Figure C2-9. 903 Pad Remediation: Estimated Annual Average Concentration Distribution of U-235

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ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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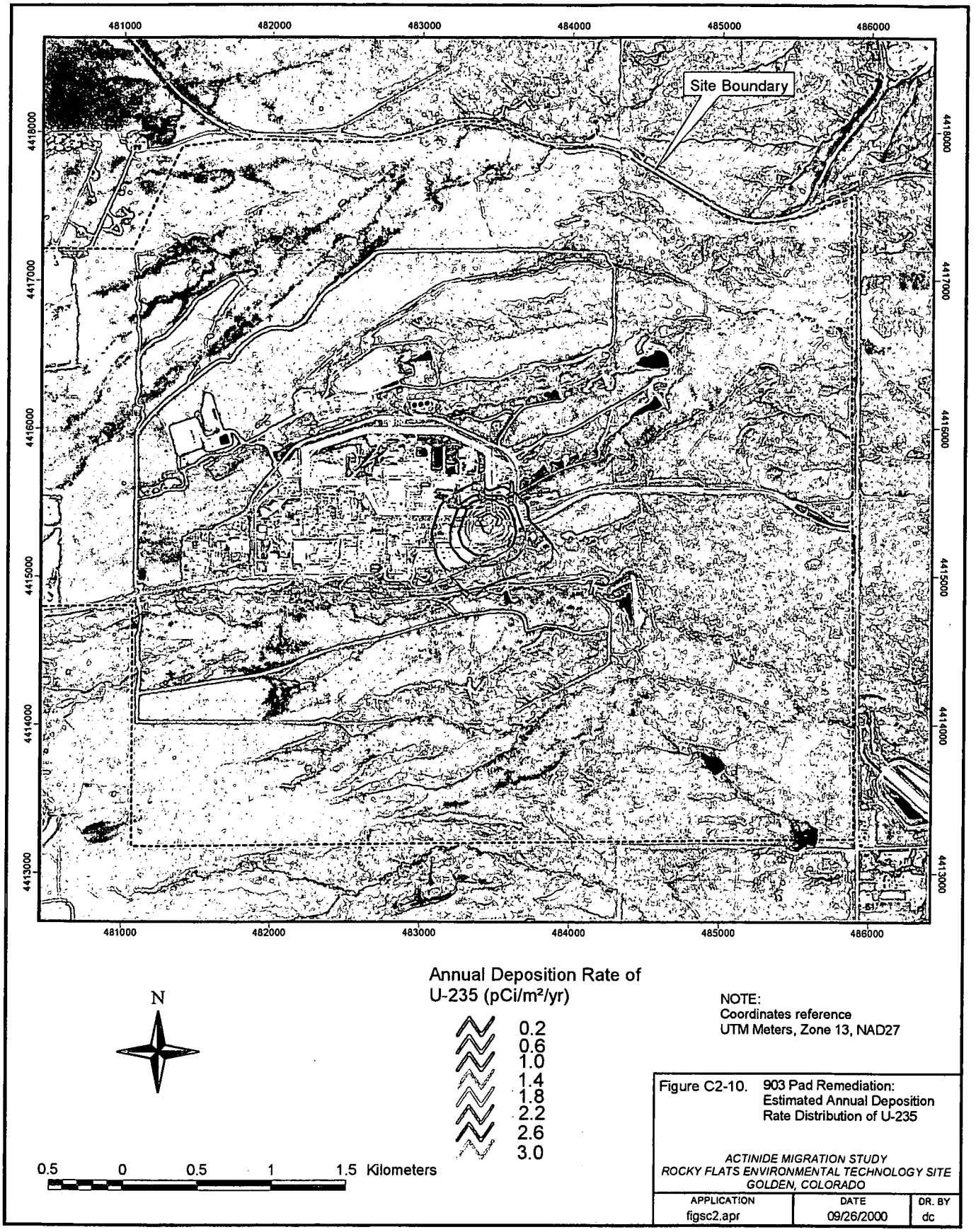

Figure C2-10. 903 Pad Remediation: Estimated Annual Deposition Rate Distribution of U-235

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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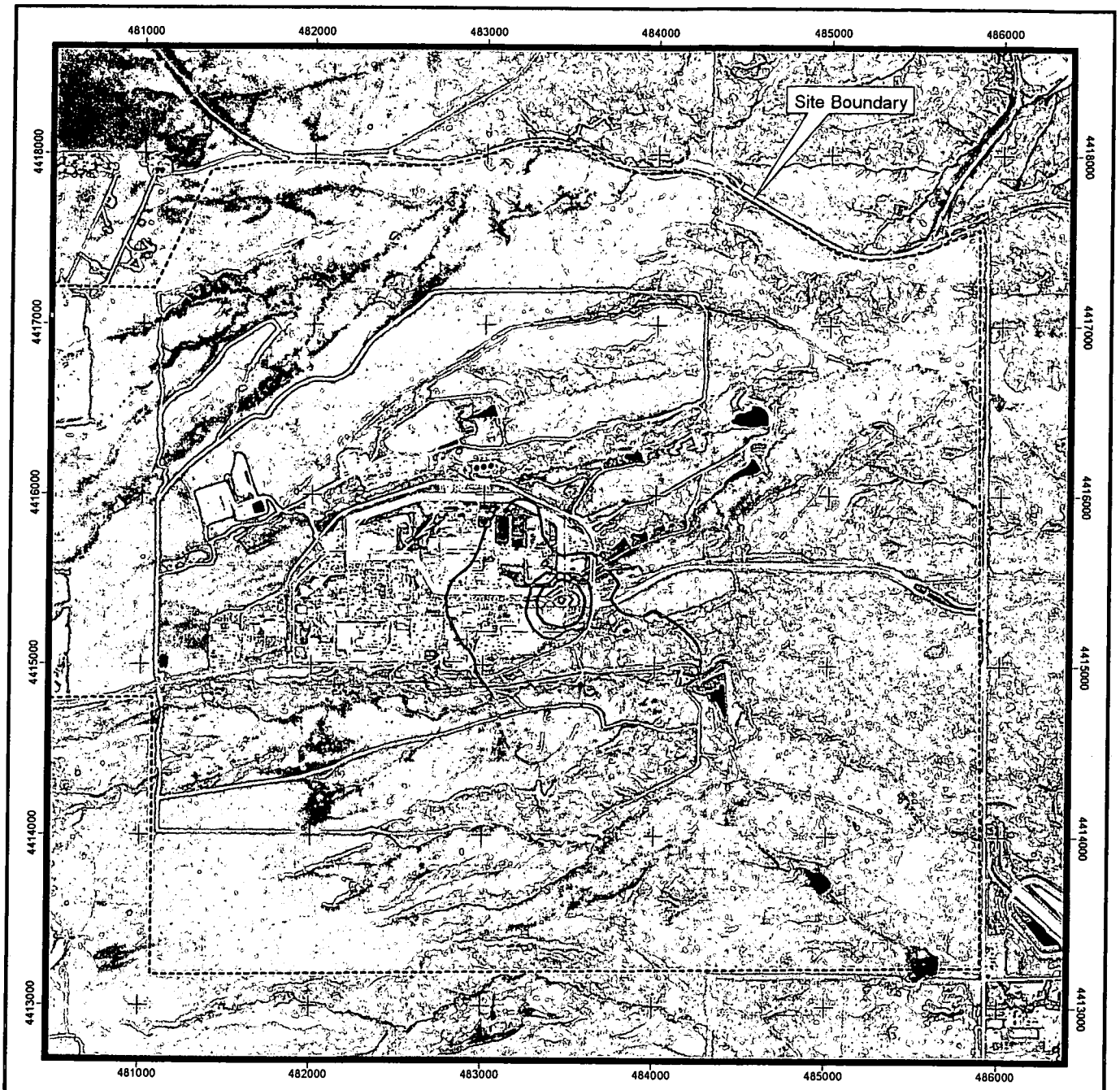

Annual Average Concentration of Activity for U-238 (pCi/m³)

- 1.0E-006
- 2.1E-006
- 4.1E-006
- 6.1E-006
- 8.1E-006
- 1.0E-004

N

0.5 0 0.5 1 1.5 Kilometers

NOTE:
Coordinates reference
UTM Meters, Zone 13, NAD27

Figure C2-11. 903 Pad Remediation: Estimated Annual Average Concentration Distribution of U-238

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Figure C2-12. 903 Pad Remediation: Estimated Annual Deposition Rate Distribution of U-238

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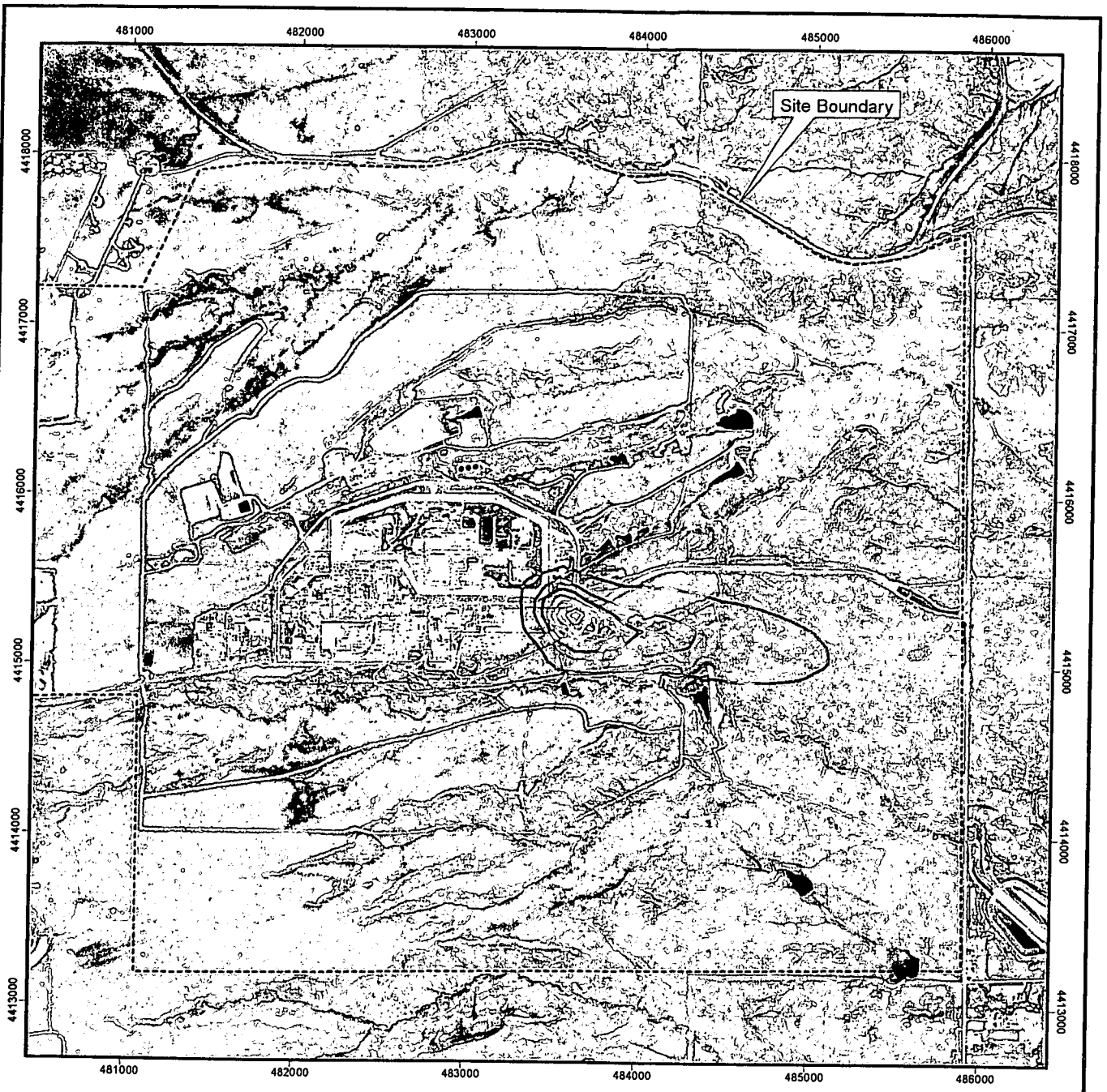

Figure C2-13. 903 Pad Remediation: Estimated 24-hour Average Concentration Distribution of PM_{10} for the High Wind Event

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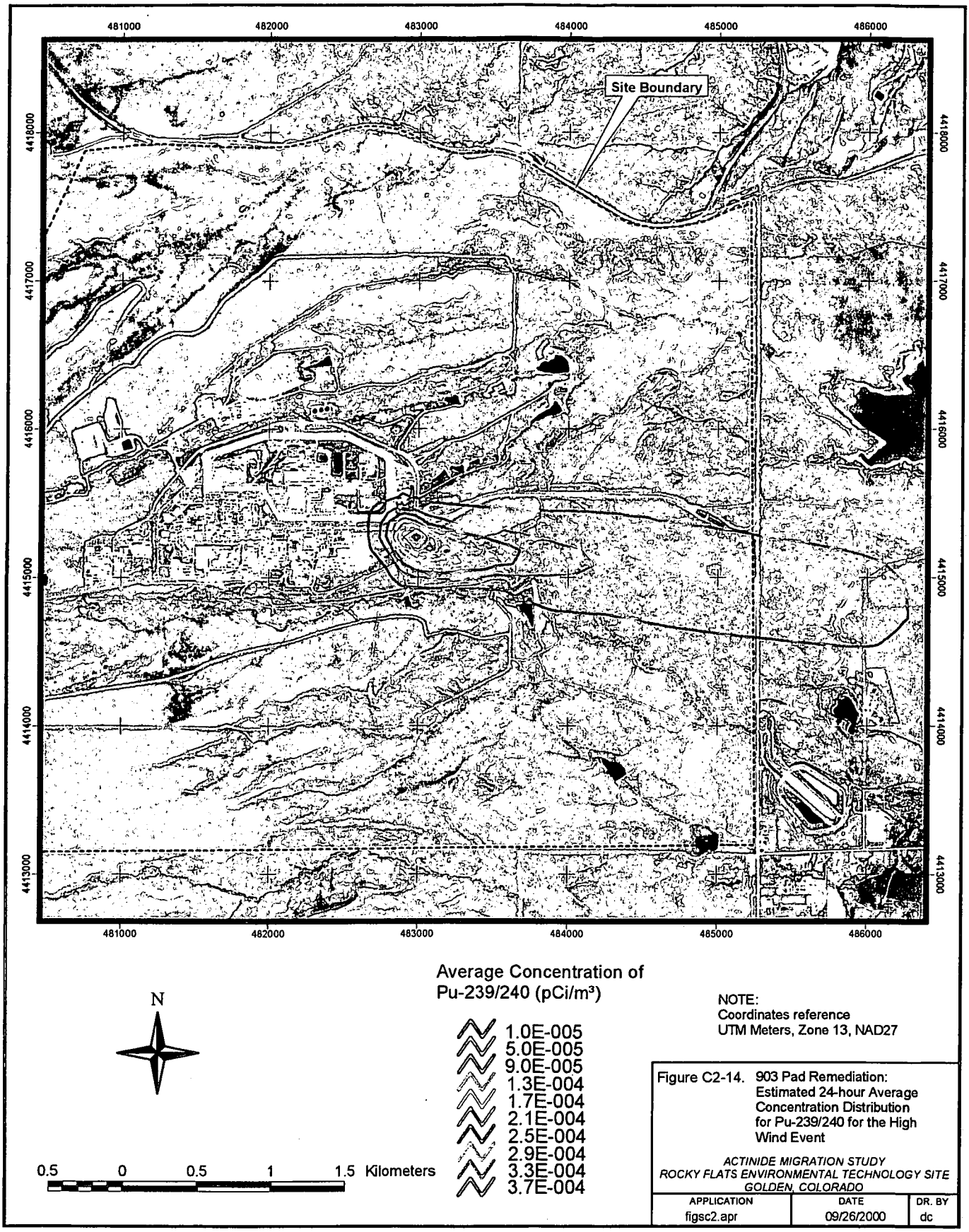

Figure C2-14. 903 Pad Remediation: Estimated 24-hour Average Concentration Distribution for Pu-239/240 for the High Wind Event

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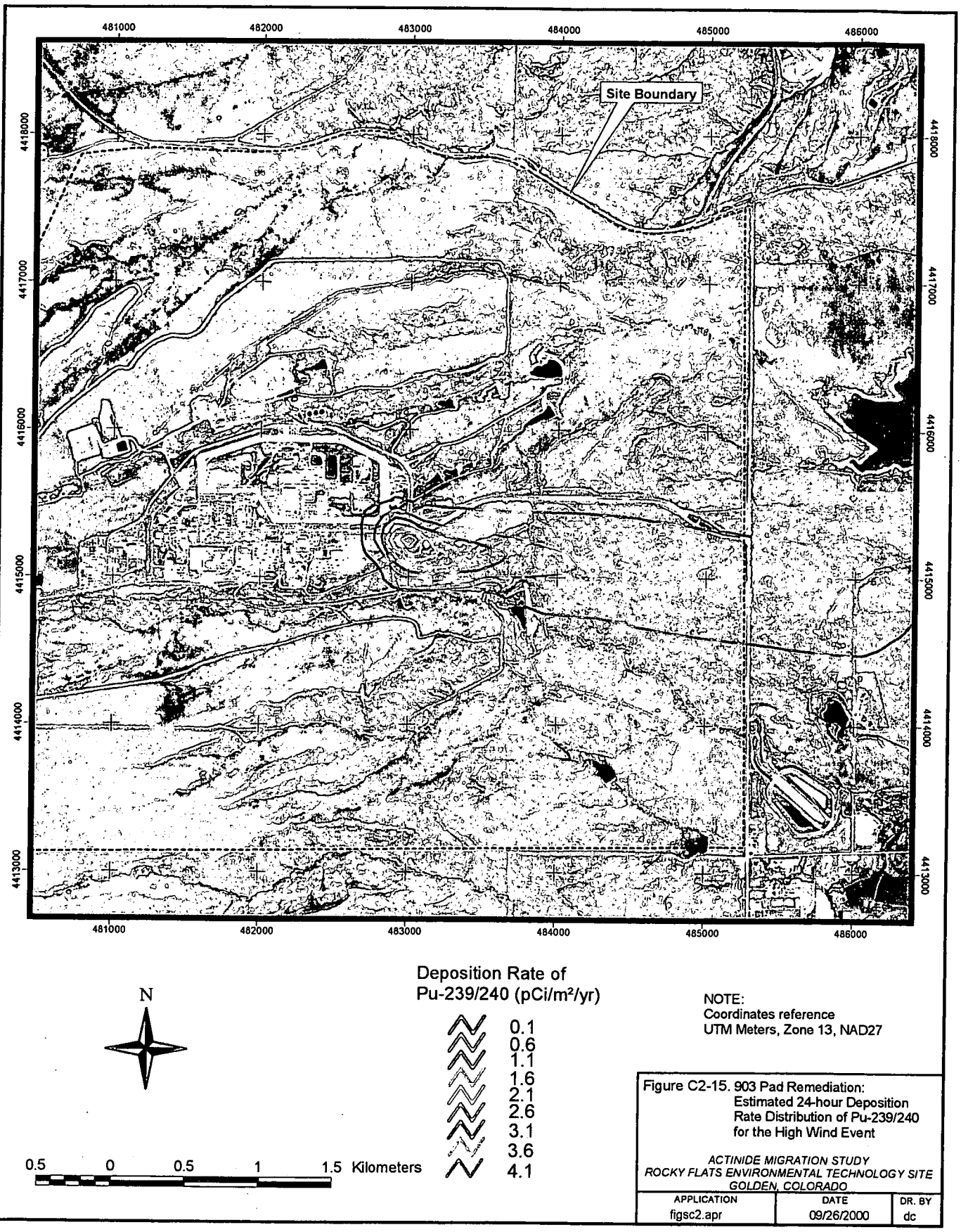

Figure C2-15. 903 Pad Remediation: Estimated 24-hour Deposition Rate Distribution of Pu-239/240 for the High Wind Event

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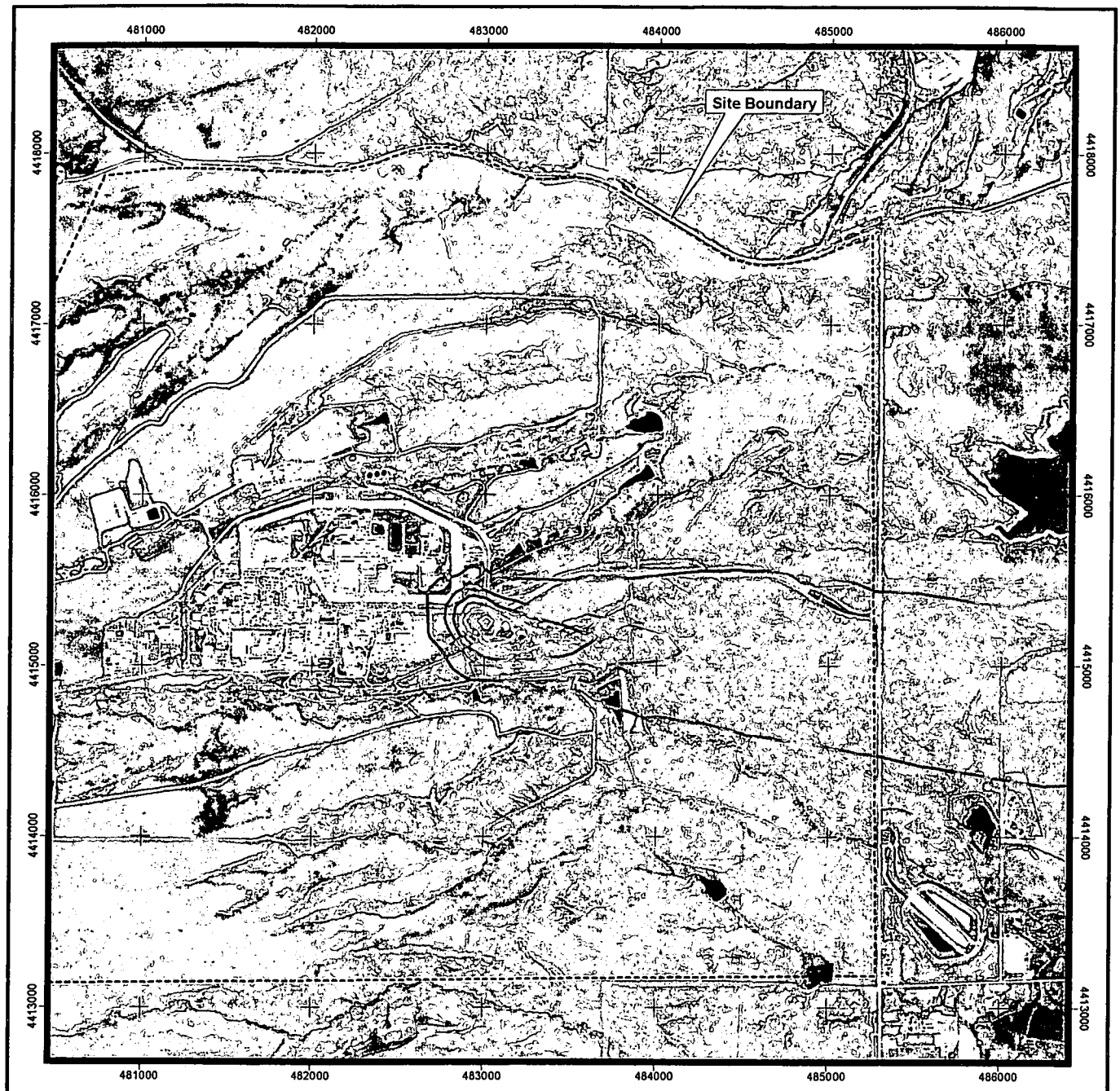

Figure C2-16. 903 Pad Remediation: Estimated 24-hour Average Concentration Distribution for Am-241 for the High Wind Event

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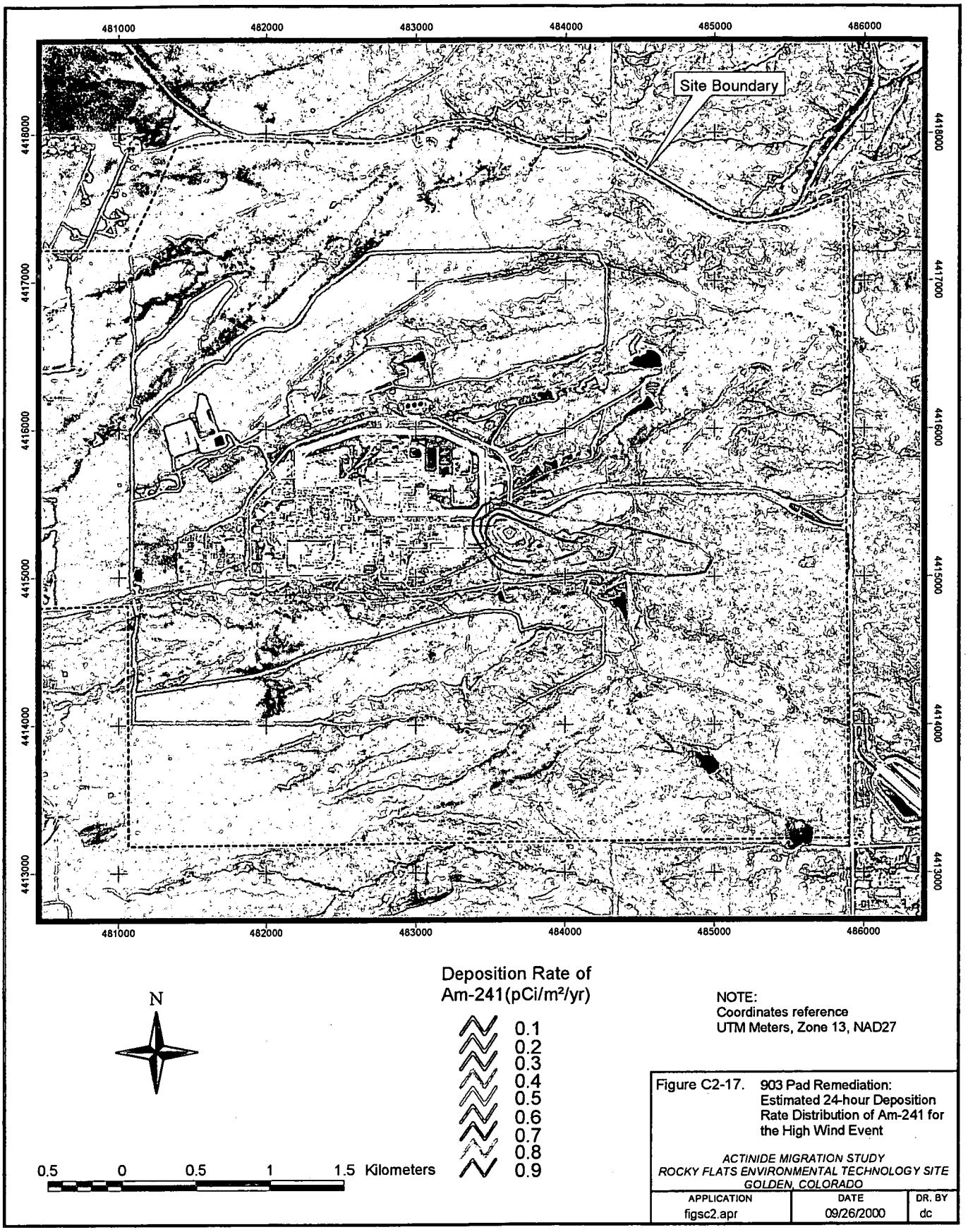

Figure C2-17. 903 Pad Remediation: Estimated 24-hour Deposition Rate Distribution of Am-241 for the High Wind Event

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Appendix D1

Decontamination and Decommissioning Emission Estimation

APPENDIX D1

DECONTAMINATION AND DECOMMISSIONING EMISSION ESTIMATION

As discussed in Section 4.1, actinide emissions were calculated for a hypothetical release during decontamination and decommissioning (D&D). The scenario assumed that a pocket of contamination would escape detection during radiological surveys and be released when the building is demolished. The contamination was assumed to be present in a fissure in a concrete wall and was assumed to be released as particulate emissions (concrete dust).

The following assumptions were made:

- The contamination would consist of Site weapons-grade plutonium (this assumption allows the americium ingrowth to be estimated);
- The contamination would be contained in a 20 foot (ft) long, 10 centimeter (cm) deep fissure in a concrete wall, penetrating the concrete to a depth of 1 cm;
- The contamination would be 1 million disintegrations per minute per 100 square centimeters (dpm/100 cm^2);
- Each particle of concrete would consist of a 74 micrometer ($\mu m = 10^{-4}$ cm) cube, based on the final screening size of Portland cement (Perry et al., 1984);
- Contamination would be released as total particulate matter (PM) during demolition of the concrete wall, or during size reduction of the concrete, at an emission rate of 0.005 pounds (lb) of PM per ton of concrete demolished (emission factor for tertiary crushing, AP-42, Table 11-19.2-2 [EPA, 1995b]);
- Concrete weighs 2.19 grams per cubic centimeter (g/cm^3) (Oberg et al., 1990);
- The release was assumed to occur over a 1-hour period from the vicinity of the Solar Ponds (see Figure 1-2); and
- The release would be a one-time occurrence.

Radionuclide emissions were calculated as described below.

- **Area of contamination would be the total surface area of contaminated particles in the fissure.**

Depth of fissure x length of fissure x penetration of contamination x two surfaces in the fissure = total volume of contaminated concrete:

$10 \text{ cm} \times 20 \text{ ft } [610 \text{ cm}] \times 1 \text{ cm} \times 2 = 12{,}200 \text{ cm}^3$

Assuming that each particle is a cube with dimensions of 74×10^{-4} cm, each particle has a volume of:

$(74 \times 10^{-4} \text{ cm})^3 = 4.05 \times 10^{-7} \text{ cm}^3$ per particle

The number of concrete particles in a cm^3 of concrete:

$$\frac{1 \text{cm}^3}{4.05 \times 10^{-7} \text{ cm}^3 \text{ per particle}}$$

$= 2.47 \times 10^6$ particles per cm^3

The total number of contaminated concrete particles:

Volume of contaminated concrete (cm^3) x number of particles:

$12{,}200 \text{ cm}^3 \times (2.47 \times 10^6 \text{ particles})$

$= 3.0 \times 10^{10}$ total contaminated concrete particles

Area of each particle (cube) is 6 times the diameter squared:

$6 \times (74 \times 10^{-4} \text{ cm})^2 = 3.29 \times 10^{-4} \text{ cm}^2$ per particle

Total surface area of contaminated particles:

Number of contaminated particles x surface area of each particle:

$(3.0 \times 10^{10}$ particles) x $(3.29 \times 10^{-4} \text{ cm}^2$ per particle)

$= 9.86 \times 10^6 \text{ cm}^2$ total surface area

- **The total contamination in the fissure can be calculated from the contaminated particle surface area and the contamination level.**

(1 million dpm/100 cm^2) x ($9.86 \times 10^6 \text{ cm}^2$ total surface area)

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$= 9.86 \times 10^{10}$ dpm

$(9.86 \times 10^{10}$ dpm) x (0.45 pCi/dpm)

$= 4.43 \times 10^{10}$ total pCi (= 0.0443 Ci)

- **The contamination that would be released during D&D can be calculated from the particulate matter emission factor and the previously calculated contaminant loading.**

Mass of contaminated concrete:

12,200 cm^3 x 2.19 g/cm^3 = 26,718 g

Contamination per gram of concrete:

$$\frac{4.43 \times 10^{10} \text{ pCi}}{26{,}718 \text{ g concrete}}$$

$= 1.66 \times 10^6$ pCi/g contaminated concrete

Emission factor is 0.005 lb(2.27g) PM per ton (907,185 g) of concrete:

$$\frac{2.27\text{g PM}}{907{,}185 \text{ g concrete}}$$

$= 2.5 \times 10^{-6}$ g PM/g concrete

Total contaminated particulate matter emitted:

(26,718 g contaminated concrete) x $(2.5 \times 10^{-6}$ g PM/g concrete)

= 0.067 g PM

Total activity released:

(0.067 g PM) x $(1.66 \times 10^6$ pCi/g)

= 1.1×10^5 total pCi emissions

Appendix D2

Decontamination and Decommissioning Modeling Methods and Results

APPENDIX D2

DECONTAMINATION AND DECOMMISSIONING MODELING METHODS AND RESULTS

This appendix describes how the decontamination and decommissioning (D&D) release was simulated in the ISCST3 model and presents the results of the modeling analyses.

D2.1 Modeling Methods

The emissions from the D&D release (Scenario 3) were modeled as a volume source with the ISCST3 model as discussed in Section 4.3. Initial dimensions for the volume source were determined from Table 3-1 in the ISCST3 user's guide (EPA, 1995a) using the factors for a "single volume source" (lateral dimensions) and "surface-based source" (vertical dimensions).

- **The initial lateral dimension (σ_{yo}) was determined as follows:**

  Length of one side of the volume source = 3 meters (m)

  σ_{yo} = length of side/4.3 = 0.70 m

- **The initial vertical dimension (σ_{zo}) was determined as follows:**

  Height of volume source = 3 m

  σ_{zo} = height of source/2.15 = 1.4 m

Estimates of the amount of activity released (described in Appendix D1) were assumed to be released in a 1-hour period. The 1-hour release rates were divided by the number of seconds in 1 hour to arrive at emission rates in picocuries per second (pCi/s) and the release rate was assumed to remain constant over an hour. The emission rate for plutonium (Pu) 239/240 was 10.26 pCi/s and the emission rate for americium (Am) 241 was 1.06 pCi/s.

D2.2 Model Results

Figures D2-1 and D2-2 show the results of the D&D scenario modeling.

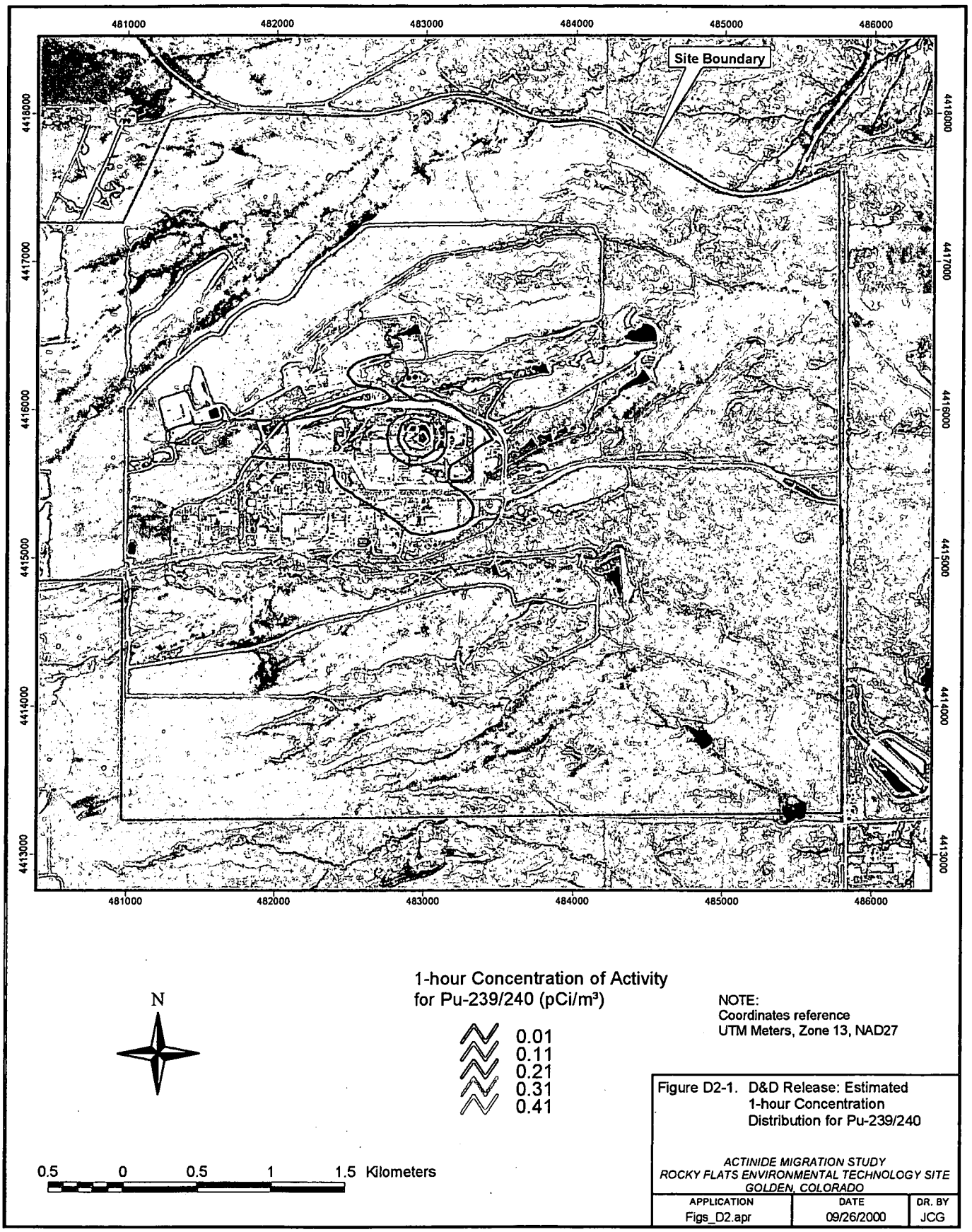

Figure D2-1. D&D Release: Estimated 1-hour Concentration Distribution for Pu-239/240

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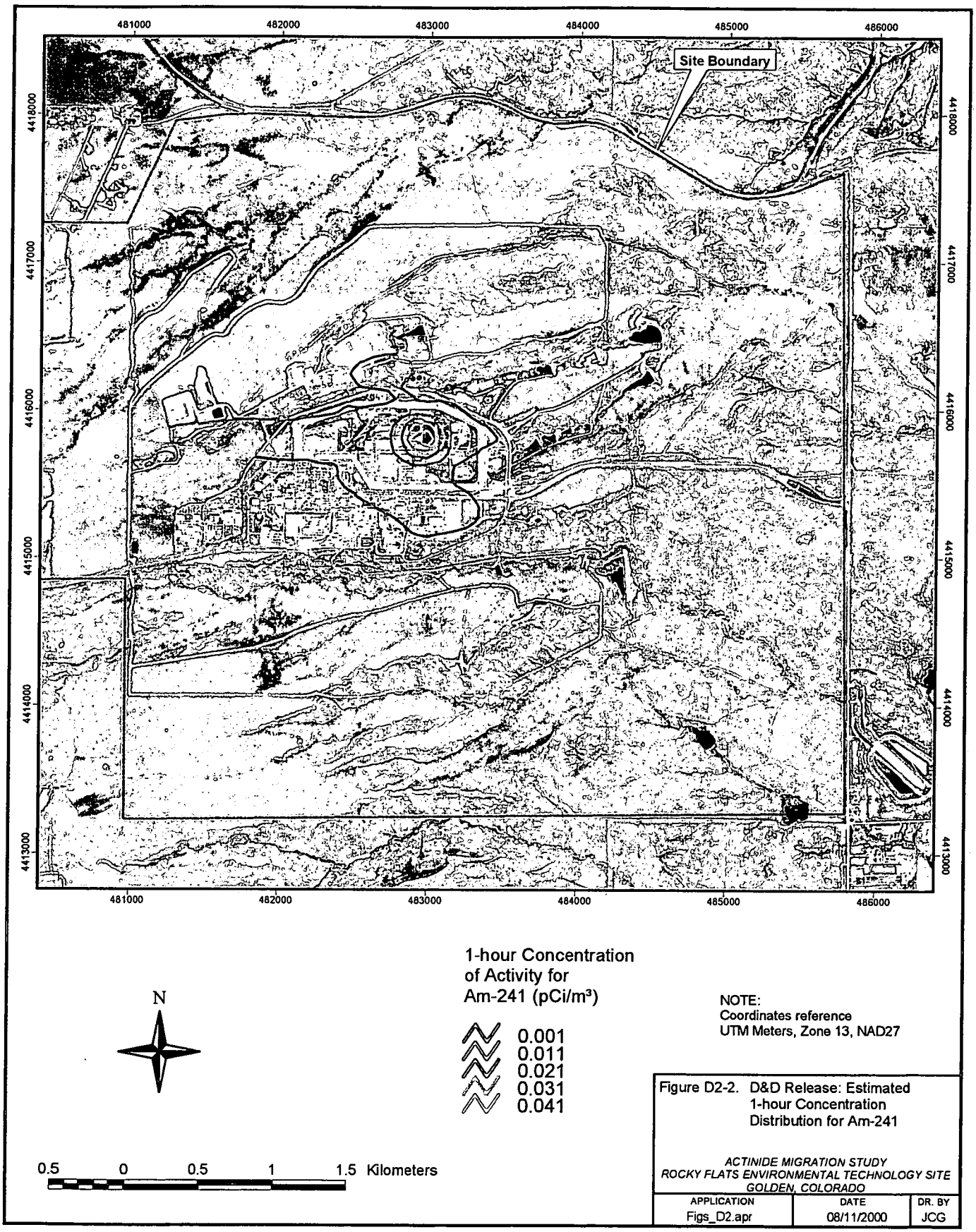

Figure D2-2. D&D Release: Estimated 1-hour Concentration Distribution for Am-241

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Appendix E1

Fire /Post Fire Scenarios Emission Estimation

APPENDIX E1

FIRE/POST FIRE SCENARIOS EMISSION ESTIMATION

This appendix details aspects of the emissions calculated for simulated wildfires and for resuspension following a fire, as described in Sections 5.1 and 5.2.

E1.1 Particulate Emission Estimation

Particulate emissions from wildfires can be calculated from the amount of fuel that is burned per unit area, the rate at which fuel is consumed, and an emission factor relating the mass of particulates released to the mass of fuel burned:

$$Q = \left(\frac{(EF)(FL)(CF)}{T} \right)$$ (Sestak and Riebau, 1988)

where:

Q is the particulate matter emission rate (mass particulates emitted per unit area per unit time; i.e., grams per square meter per second [$g/m^2/s$]);
EF is the emission factor (in mass particulates emitted per mass fuel burned [g/g]);
FL is the fuel loading (mass fuel per unit area [g/m^2]);
CF is the fuel consumption factor (proportion of available fuel consumed in the fire); and
T is the total duration of fire (seconds [s]).

This formula estimates particulate emissions from wildfires in the units required by the dispersion model used in this study. The emissions from an entire fire would be a function of the total area burned. A closer examination of each factor in above equation follows.

E1.1.1 Particulate Emission Factors

The low near-soil heat and turbulence observed during the April 2000 test burn at the Site suggested that soil mobility due to actual grassland fire turbulence would be minimal. A shallow soil temperature monitor buried in the prescribed burn plot recorded a peak temperature of 195 degrees Celsius (°C) during the fire, and no visible stirring of soils was apparent in the wake of that fire (see Figure E1-1). The particulate emissions from the prescribed fire, then, were attributed to ashed plant material and resuspended soil particles attached to plant material. These conclusions were applied to the wildfire scenario in selecting emission factors.

For this study, particulate emission factors were taken from Leenhouts (1998), as shown in Table E1-1. These factors have been used in a recent update to the Simple Approach Smoke Estimation Model (SASEM), and are specific to western perennial grassland fires.

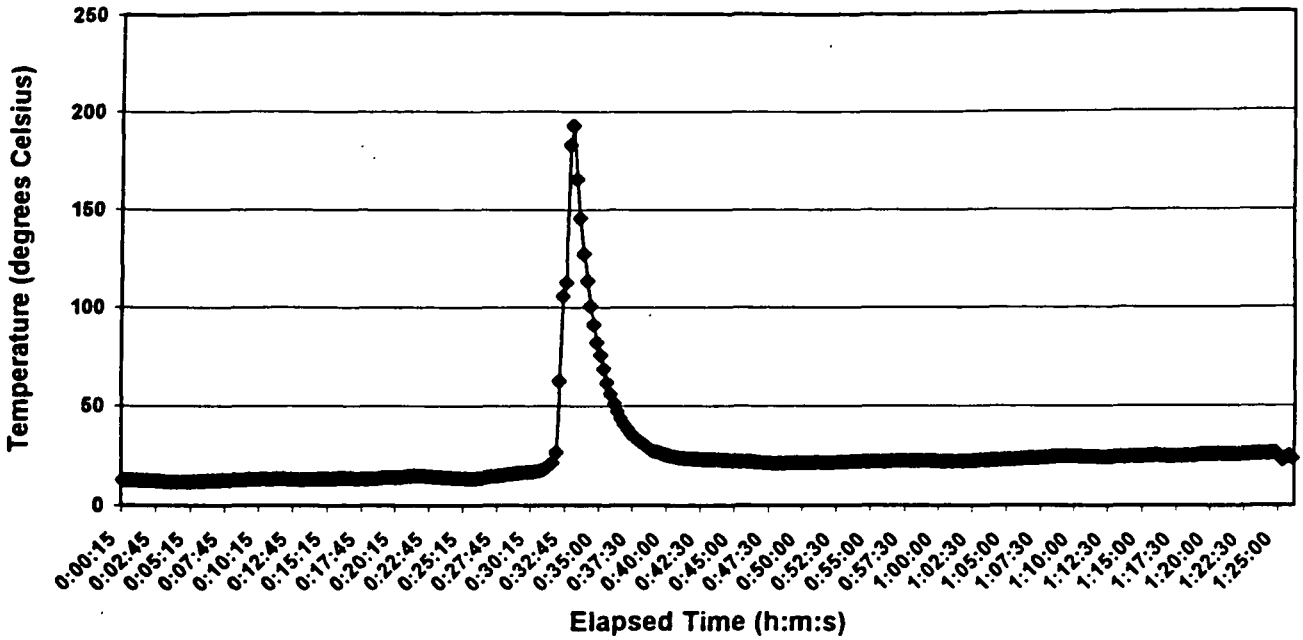

Figure E1-1. Surficial Soil Temperature at One Location for Test Burn

Table E1-1. Particulate Emission Factors for Western Perennial Grassland Fires[a]

Particle Size (μm)	Litter EF (g PM/g fuel)	Vegetation EF (g PM/g fuel)
≤2.5	0.0039	0.0106
≤10	0.0046	0.0125
≤30	0.0073	0.0164

[a]From Leenhouts, 1998.

Notes:
EF = emission factor
g = grams
PM = particulate matter
μm = micrometer

E1.1.2 Fuel Loading and Consumption Factors

For this study, empirically determined vegetation mass values obtained at various locations on Site were assumed to represent available fuel. Table E1-2 summarizes fuel loading values from Site vegetation. For the 903 Pad wildfire scenario, reclaimed and mesic grasses cover the burn area. To account for increases in standing vegetation and litter resulting from summer growth, compared to the 1994 data obtained in early spring, the 1994 values were scaled upward by 20 percent.

Table E1-2. Biomass Values for Fuel Loading Calculations[a]

Community	Biomass Type	1993-1994 Mean (g/m^2)	1994 Scaled to September[b] (g/m^2)
Xeric	Current year production	126.4	—
	Litter	189.4	—
Mesic	Current year production	118.8	144.1
	Litter	191.1	270.0
Reclaimed	Current year production	129.7	175.0
	Litter	189.0	273.0

[a]Site measurements of representative plant communities, spring 1993, 1994.
[b]1994 mesic and reclaimed biomass data scaled upward by 20% to reflect expected summer growth prior to September fire event.
[c]Xeric communities sampled before April test burn.
Notes:
g/m^2 = grams per square meter
— = not applicable

For standing grasses, it was assumed that 50% of total biomass would be consumed. For litter, the consumed proportion was assumed to be 90% (Leenhouts, 1998).

E1.1.3 Fire Duration Factors

For these wildfire scenarios, the burn duration was determined through the use of the fire behavior model BEHAVE, developed by federal land management agencies (Andrews and Bevins, 1998). The following assumptions were employed in the BEHAVE model:

- Fires begin: 1600 local time on September 15th;
- Fire location: 903 Pad area
- Wind direction: from due west (270 degrees) for the duration of the fire;
- Sky conditions: 70% cloud cover due to approaching thunderstorm;
- Ground elevation: 6,000 feet;
- Total area consumed: 109 acres;
- Grasses: <12 inches in height;
- Fuel moisture: 2%;
- Relative humidity: 15%;
- Air temperature: 80 degrees Fahrenheit (°F); and
- Average slope angle of the burn plot: 15 degrees north to south toward the South Interceptor Ditch (SID).

Wind speed was incremented in the BEHAVE model between 1 meter per second (m/s) and 5 m/s at 0.5 m/s intervals, then stepped to 8, 10, 15, and 20 m/s, producing a range of fire duration for a presumed burn area of 109 acres. Fire durations for the indicated wind speeds are shown in Table E1-3.

Table E1-3. Fire Duration as a Function of Wind Speed[a]

Wind Speed (m/s)	Fire Duration (hours)	Fire Duration (seconds)
1.0	3.3	11,880
1.5	2.7	9,720
2.0	2.1	7,560
2.5	1.6	5,760
3.0	1.3	4,680
3.5	1.0	3,600
4.0	0.85	3,060
4.5	0.65	2,340
5.0	0.55	1,980
8.0	0.25	900
10.0	0.20	720
15.0	0.15	540
20.0	0.15	540

[a] For a presumed burn area of 109 acres.
Note:
m/s = meters per second

E1.2 Actinide Emission Estimates

For this model, actinides were assumed to reside in soil particles attached to plant surfaces and, to a lesser degree, to reside within plant tissues due to root uptake. Soil contamination levels in the areas burned (see Table E1-4, below) were used to convert mass particulate emissions to activity units for various isotopes of interest, subject to the variables described below. Total actinide emissions are the sum of the attached soil isotopic emissions (E_a) and the plant-contained isotopic emissions (E_p) (see Sections E1.2.1 and E1.2.2).

Note that plutonium (Pu) 239/240 concentrations in the high concentration subplot were assumed to **increase** following remediation. While this appears to be counterintuitive, the result stems from the fact that the most contaminated soils are currently located **under** the asphalt pad. Cleanup will expose these soils.

While the most contaminated soils will be removed (i.e., those above Tier I levels and co-located Tier II soils), the remaining soils will still exhibit higher average Pu-239/240 levels than the surrounding area.

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Table E1-4. Average Soil Actinide Concentrations in Wildfire Subplots

Subplot	Current Conditions (Pre-Remediation)		Post-Closure (Post-Remediation)	
	Pu-239/240 (pCi/g)	Am-241 (pCi/g)	Pu-239/240 (pCi/g)	Am-241 (pCi/g)
High concentration	250	100	350	100
Low concentration	20	4	20	4

Note:
Am = americium
pCi/g = picocuries per gram
Pu = plutonium

E1.2.1 Mass Loading

The value 134 milligrams soil per gram plant material (mg/g) (=0.134 g/g) was used to differentiate particulate emissions from plant-attached soil from those derived from combustion products. This value is based on data obtained from measurements on and near the Site, as reported by Arthur and Alldredge (1982). This value was conservatively derived from the following table by using the autumn average plus one standard deviation of error:

Table E1-5. Attached Soil Mass per Unit Plant Mass[a]

Measurement	Spring (mg/g)	Autumn (mg/g)	Winter (mg/g)
Soil attachment in grams of soil per gram of vegetation (dry weight)	5	44	13
Standard deviation	3	90	18

[a] Arthur and Alldredge, 1982
Notes:
mg/g = milligrams of soil per gram vegetation

All plant-attached soil was assumed to be emitted as fine particulate matter less than or equal 10 micrometers (PM_{10}) when the plant is consumed by fire. This provides a conservative estimate of the inhalable particulate emission rate from this source. The equation for estimating actinide emissions from plant-attached soil is:

$$E_a = Ca\left(\frac{0.134}{E_{PM\,10}}\right)$$

where:

E_a is the emission rate per unit area of the isotope of interest, in picocuries per square meter per second (pCi/m^2/s);
0.134 is the soil attachment coefficient, in g soil/g plant material (g/g);
$E_{PM_{10}}$ is the PM_{10} emission flux, in g/m^2/s; and
C_a is the soil concentration of the isotope of interest, in picocuries per gram (pCi/g).

E1.2.2 Plant Uptake

The uptake of actinides by plants was significant for some isotopes. Baes, et al. (1984) estimated average transfer coefficients for both vegetative and reproductive plant tissues for elements of interest:

- Plutonium isotopes: 4.5×10^{-4} (vegetative), 4.5×10^{-5} (reproductive);
- Americium isotopes: 0.0055 (vegetative), 2.5×10^{-4} (reproductive); and
- Uranium isotopes: 0.0085 (vegetative), 0.004 (reproductive).

Based on these transfer coefficients, uptake from soils may be estimated using the following equation:

$$E_p = (E_{PM_{10}})(TC)(C_a)$$

where:

E_p is the emissions rate per unit area of the isotope of interest, in pCi/m^2/s;
TC is the transfer coefficient, in (pCi/g biomass)/(pCi/g soil);
$E_{PM_{10}}$ is the PM_{10} emission flux, in g/m^2/s; and
C_a is the soil concentration of the isotope of interest, in pCi/g.

Appendix E2

Fire/Post-Fire Modeling Methods and Results

APPENDIX E2

FIRE/POST-FIRE MODELING METHODS AND RESULTS

This appendix describes model input parameters specific to the fire and post-fire simulations and presents the results of the various scenarios.

E2.1 Fire Input Parameters

The pre-closure and post-closure hypothetical fires were modeled as two area sources in ISCST3, with a release height above the ground of 0.0 meters (m), an initial vertical dimension based on estimated plume rise (discussed below), and lateral dimensions based on the size of the burned area (see Figure 5-1). The high and low concentration areas were assumed to burn simultaneously.

The plume rise from a wildfire is a function of the heat release rate. The heat release rate (and, for a limited burn area, the subsequent duration of the fire) is a function of wind speed. The faster the winds, the more rapidly a fire will spread and consume fuel, leading to a hotter fire with a plume that rises further above the ground. (Only at the highest wind speeds would the wind itself suppress plume rise sufficiently to overcome the increased heat release.) While a wind-driven fire may burn many more acres before it can be brought under control, much of the pollution occurs above the breathing zone of people on the ground. Consequently, groundlevel pollutant concentrations are often lower with a hot, rapidly burning fire than with a cool, slowly spreading fire.

The hypothetical wildfires that were the subject of these simulations were assumed to begin late in the afternoon of a late September day when fuel load would be at its annual maximum. The subsequent fire behavior and dispersion, however, were based on a range of possible wind speed/stability class combinations to ensure that a worst-case combination was identified. Stability refers to the tendency for vertical motion in the atmosphere. If the atmosphere is unstable, vertical motion is enhanced. If the atmosphere is stable, vertical motion is reduced or damped. If the atmosphere is neutral, vertical motion is neither enhanced nor reduced.

The wind speed/stability class combinations that were used are shown in Table E2-1.

The BEHAVE model (Andrews and Bevins, 1998) was used to estimate fire duration for each wind speed/stability class combination. The fire duration was used in emission estimation and in calculating plume rise and the initial vertical dimension for each ISCST3 area source. The modeling paired the individual 1-hour wind/stability assumptions with the appropriate emission rates and initial vertical dimensions.

Table E2-1. Wind Speed and Stability Class Combinations Used for Hypothetical Wildfire Modeling

Wind Speed (m/s)	Stability Classes[a]
1	A-F
1.5	A-F
2	A-F
2.5	A-F
3	A-F
3.5	B-F
4	B-F
4.5	B-E
5	B-E
8	C-D
10	C-D
15	D
20	D

[a] Stability classes vary from A, which is the most unstable, through D, considered neutral, to F, the most stable. Classes E and F only occur at night.

Notes:
m/s = meters per second

The initial vertical dimension of the area sources was estimated using a method described by Sestak and Riebau (1988) in the user's guide to the Simple Approach Smoke Estimation Model (SASEM). The method assumes that the heat produced by a fire line does not produce a single coherent plume. The average depth of the fire line is used as the characteristic dimension that determines what proportion of the heat of the fire acts to raise the plume along any part of its length. The length of the fire line is divided by the fire depth to obtain a number of "plumes" by which the line can be represented. The total heat output of the fire is then divided by the number of plumes to produce the heat output used for plume rise calculations.

The depth of the fire line is calculated as:

$D = (FR)(RT)$ (Sestak and Riebau, 1988)

where:

D is the depth of the fire line;
FR is the rate of spread of the fire; and
RT is the residence time of the fire.

Default residence times for various fuels are given in Sestak and Riebau (1988); for grass, the default time is 120 seconds.

The rate of spread of the fire was calculated from the assumed area of the burn and the fire duration (i.e., FR = length of side of burn/duration of burn). Fire duration was calculated for each wind speed using BEHAVE.

Once the depth of the fire line was determined for each wind speed, the length of the fire line (a function of the size and shape of the area burned and the presumed direction of spread) was divided by the depth to calculate the number of plumes in the fire line. The number of plumes was used to calculated the heat release for an individual plume:

$$QH = (HC)\left(\frac{F}{NP}\right)$$ (Sestak and Riebau, 1988)

where:

QH is the heat release for an individual plume (in calories per second, cal/s);
HC is the heat content of fuel (heat per mass burned);
F is the fuel consumption rate (mass fuel per unit area); and
NP is the number of plumes.

Default values for HC are also given in Sestak and Riebau (1988) for various fuels; the default for grass is 3.33 megacalories per kilogram (Mcal/kg).

Fuel consumption rate was calculated as follows:

$$F = (CF)(FL)\left(\frac{A}{T}\right)$$ (Sestak and Riebau, 1988)

where:

F is the fuel consumption rate;
CF is the fuel consumption factor (see Appendix E1);
FL is the fuel loading (mass per unit area; see Appendix E1);
A is the area burned; and
T is the fire duration.

Once the heat release of each plume was determined, plume rise was calculated. Sestak and Riebau (1988) give the following formulae:

$$H = 0.0101\left(\frac{QH^{0.75}}{U}\right)$$ for stability A to D and QH < 1.4 x 10^6 cal/s

$$H = 0.0847\left(\frac{QH^{0.6}}{U}\right)$$ for stability A to D and QH > 1.4 x 10^6 cal/s

$H = 0.917\ QH^{0.33}\ U^{0.33}$ for stability E and F

where:

H is the maximum height of the smoke plume (m);
QH is the heat release rate for a section of fire that contributes to plume rise (cal/s): and
U is the average wind speed during burn (in meters per second, m/s).

Once plume rise was calculated for each wind speed/stability class combination, the initial vertical dimension of the area sources representing the wildfire were determined. The *User's Guide for the Industrial Source Complex (ISC3) Dispersion Models, Volume I—User Instructions* (EPA, 1995a) recommends setting the initial vertical dimension to the plume height divided by 2.15 for surface-based sources, such as a fire.

E2.2 Model Results

The results of the wildfire and post-fire recovery modeling are shown in Figures E2-1 through E2-18. The results are discussed in Sections 5.1 and 5.2 of this report.

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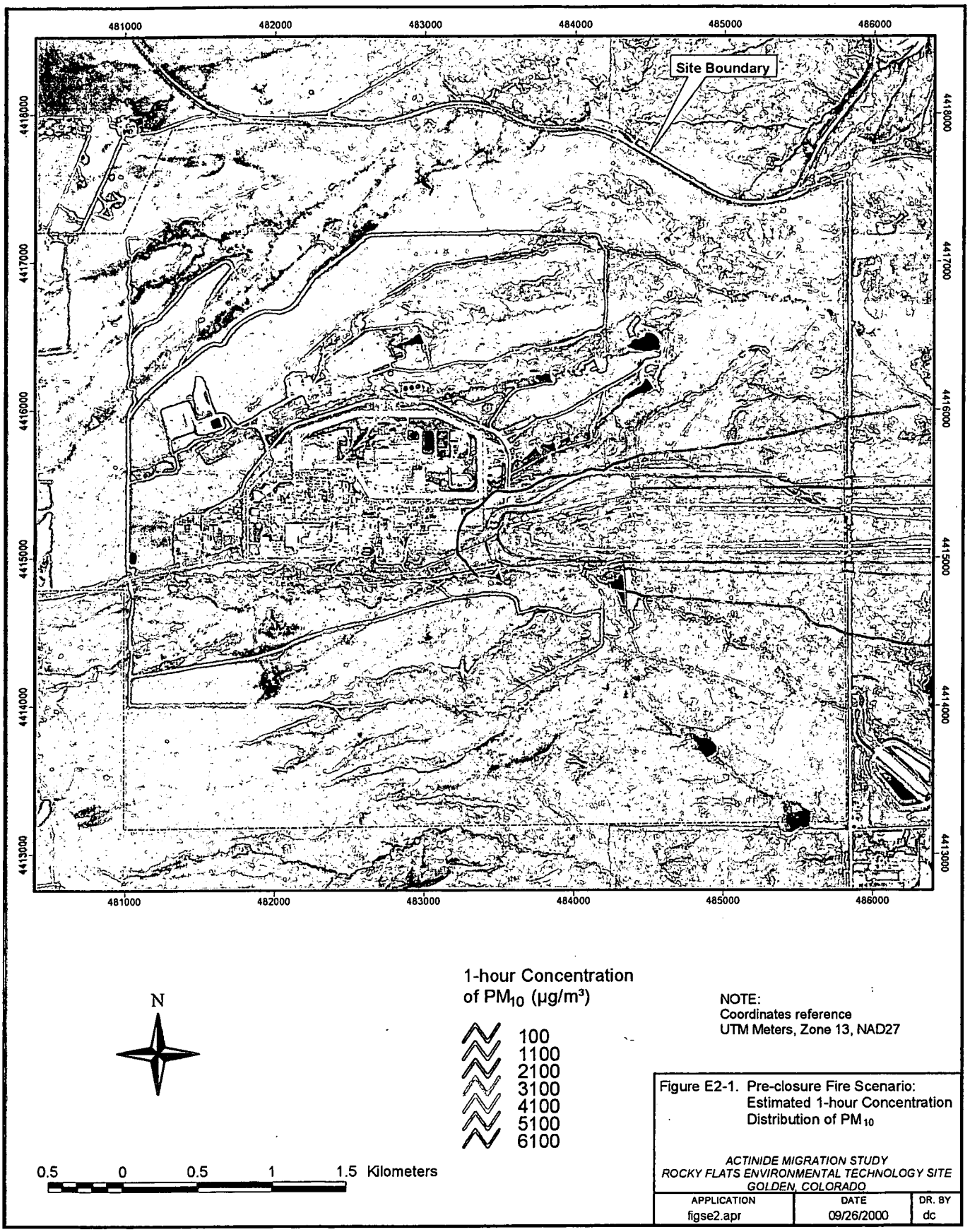

Figure E2-1. Pre-closure Fire Scenario: Estimated 1-hour Concentration Distribution of PM_{10}

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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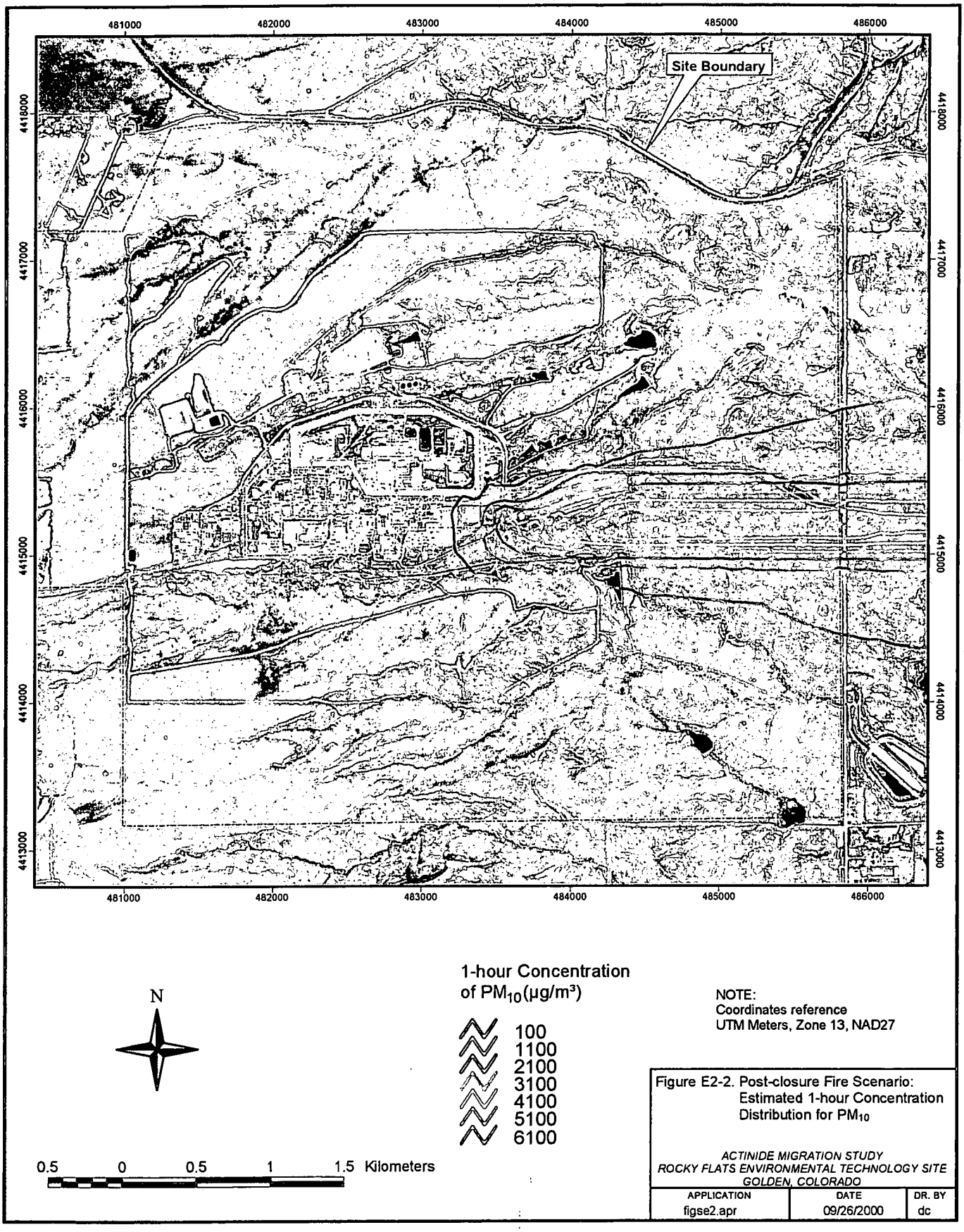

Figure E2-2. Post-closure Fire Scenario: Estimated 1-hour Concentration Distribution for PM_{10}

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ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
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Figure E2-3. Pre-closure Fire Scenario: Estimated 1-hour Concentration Distribution for Pu-239/240

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ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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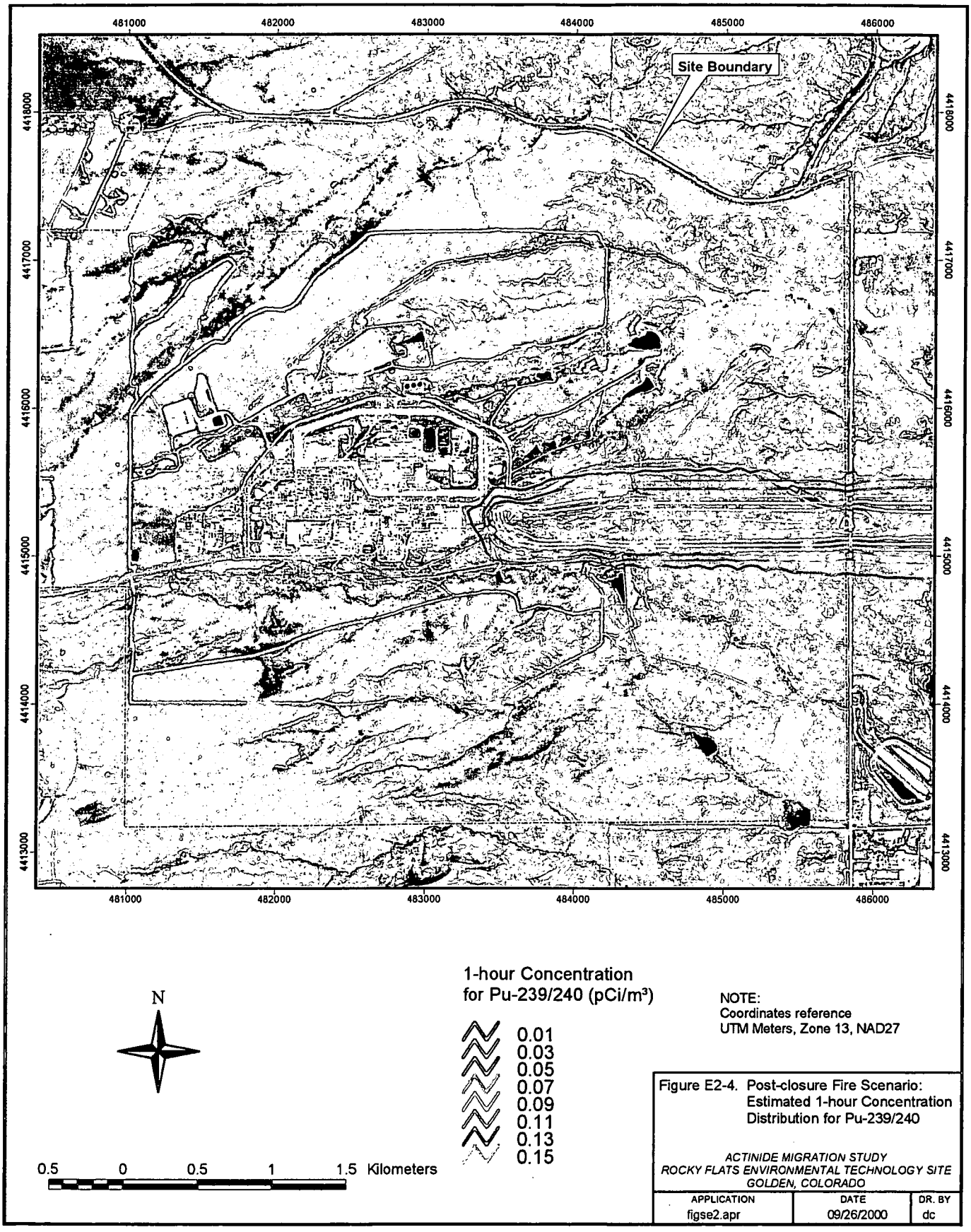

Figure E2-4. Post-closure Fire Scenario: Estimated 1-hour Concentration Distribution for Pu-239/240

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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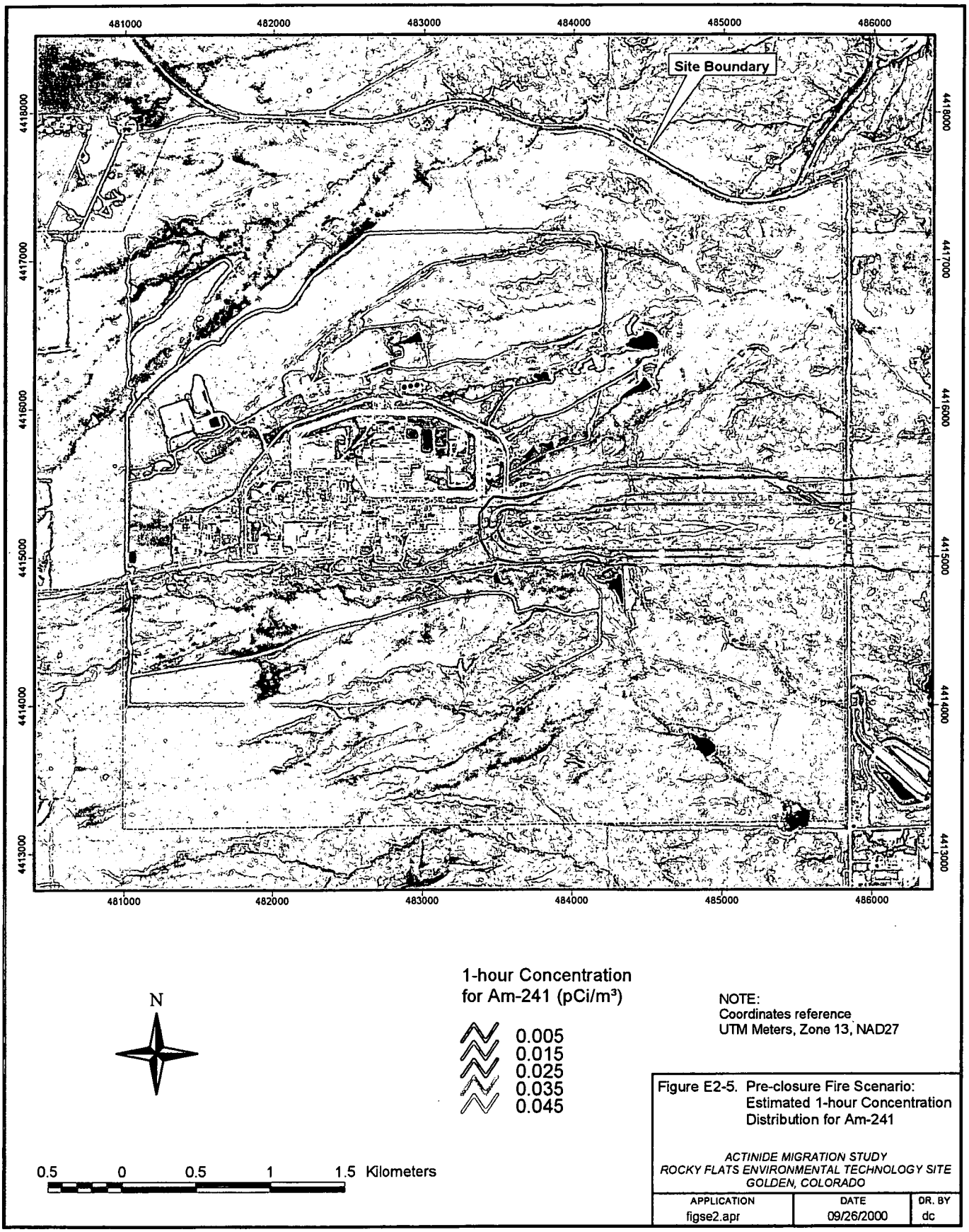

Figure E2-5. Pre-closure Fire Scenario: Estimated 1-hour Concentration Distribution for Am-241

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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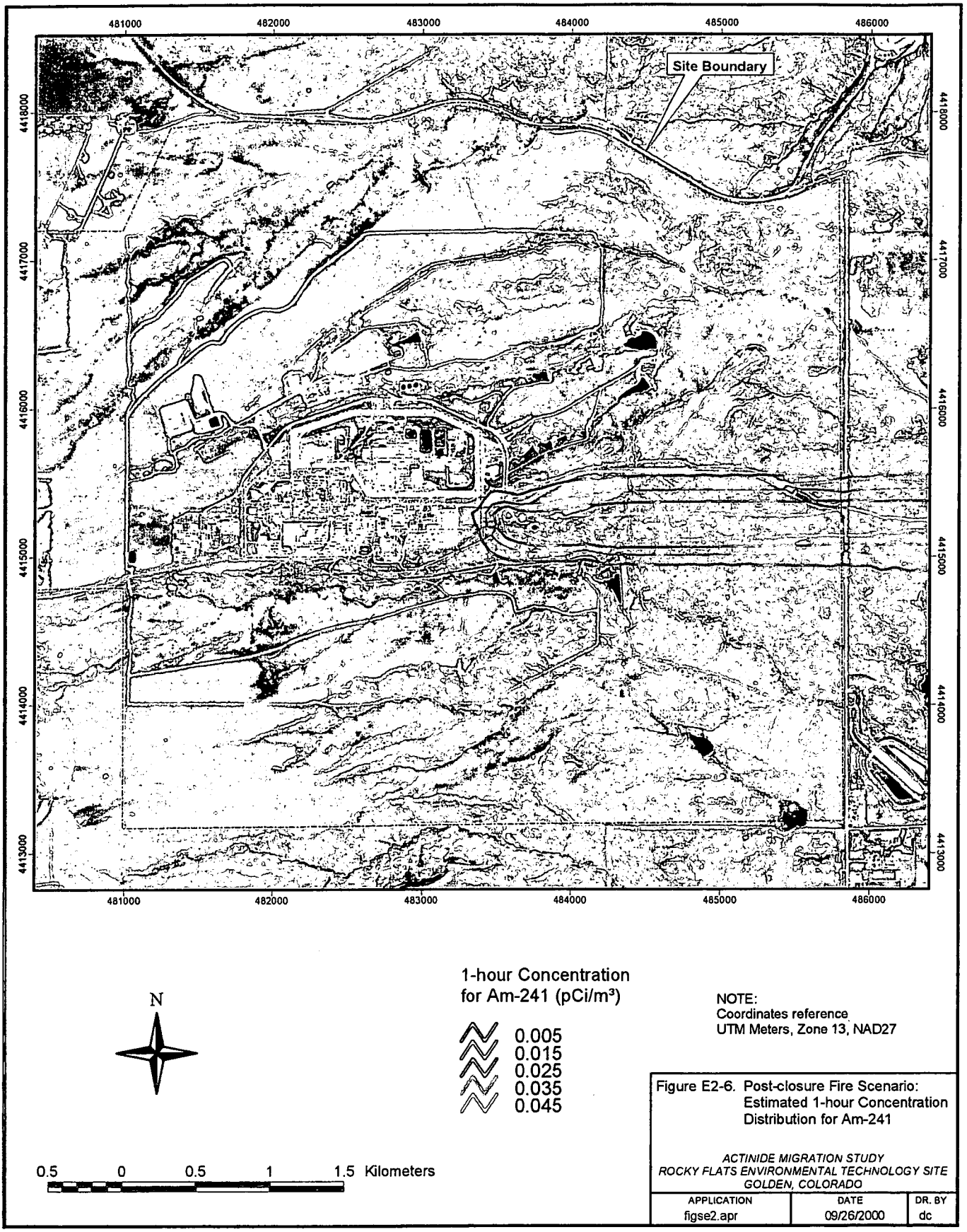

Figure E2-6. Post-closure Fire Scenario: Estimated 1-hour Concentration Distribution for Am-241

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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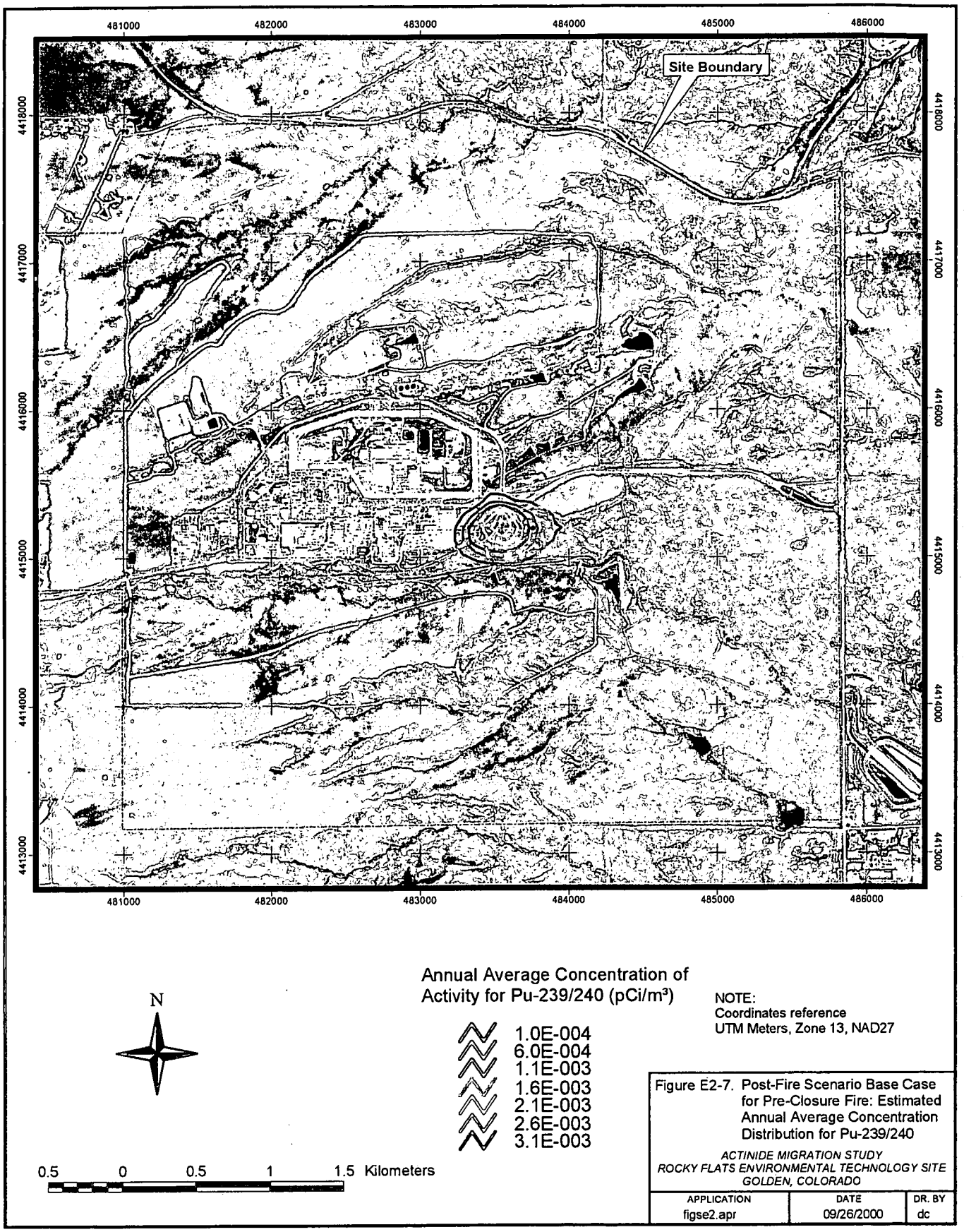

Figure E2-7. Post-Fire Scenario Base Case for Pre-Closure Fire: Estimated Annual Average Concentration Distribution for Pu-239/240

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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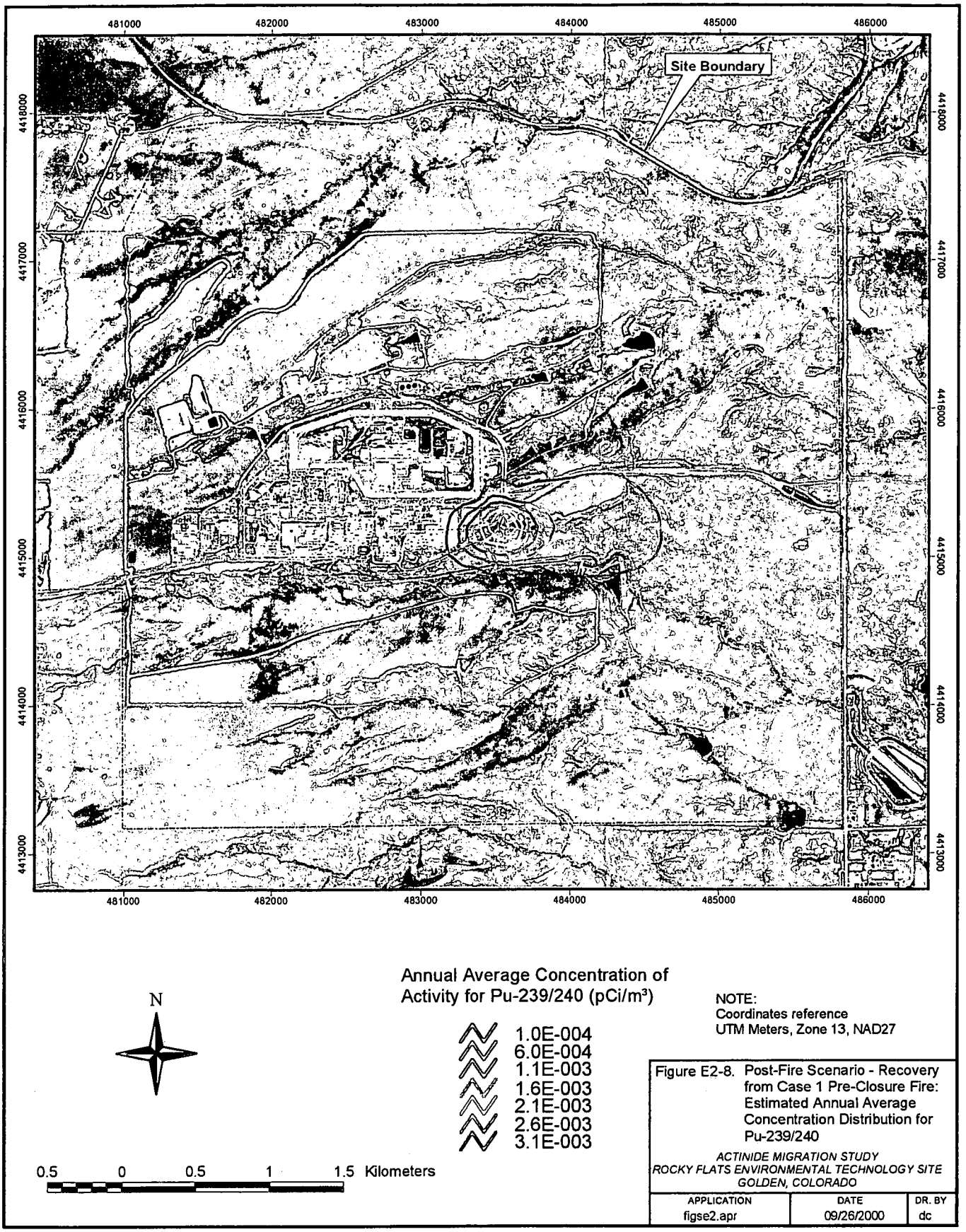

Figure E2-8. Post-Fire Scenario - Recovery from Case 1 Pre-Closure Fire: Estimated Annual Average Concentration Distribution for Pu-239/240

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

APPLICATION	DATE	DR. BY
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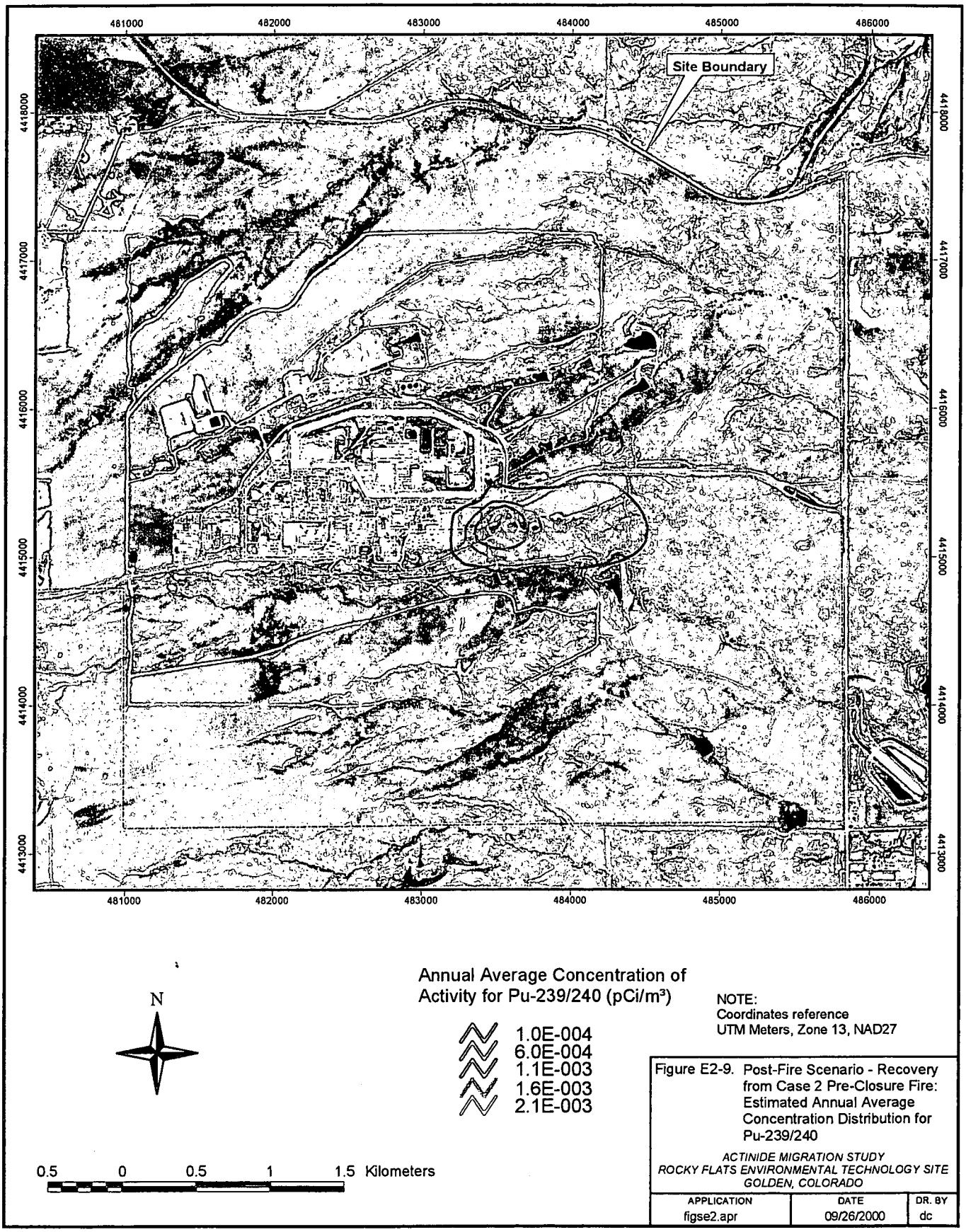

Figure E2-9. Post-Fire Scenario - Recovery from Case 2 Pre-Closure Fire: Estimated Annual Average Concentration Distribution for Pu-239/240

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

APPLICATION	DATE	DR. BY
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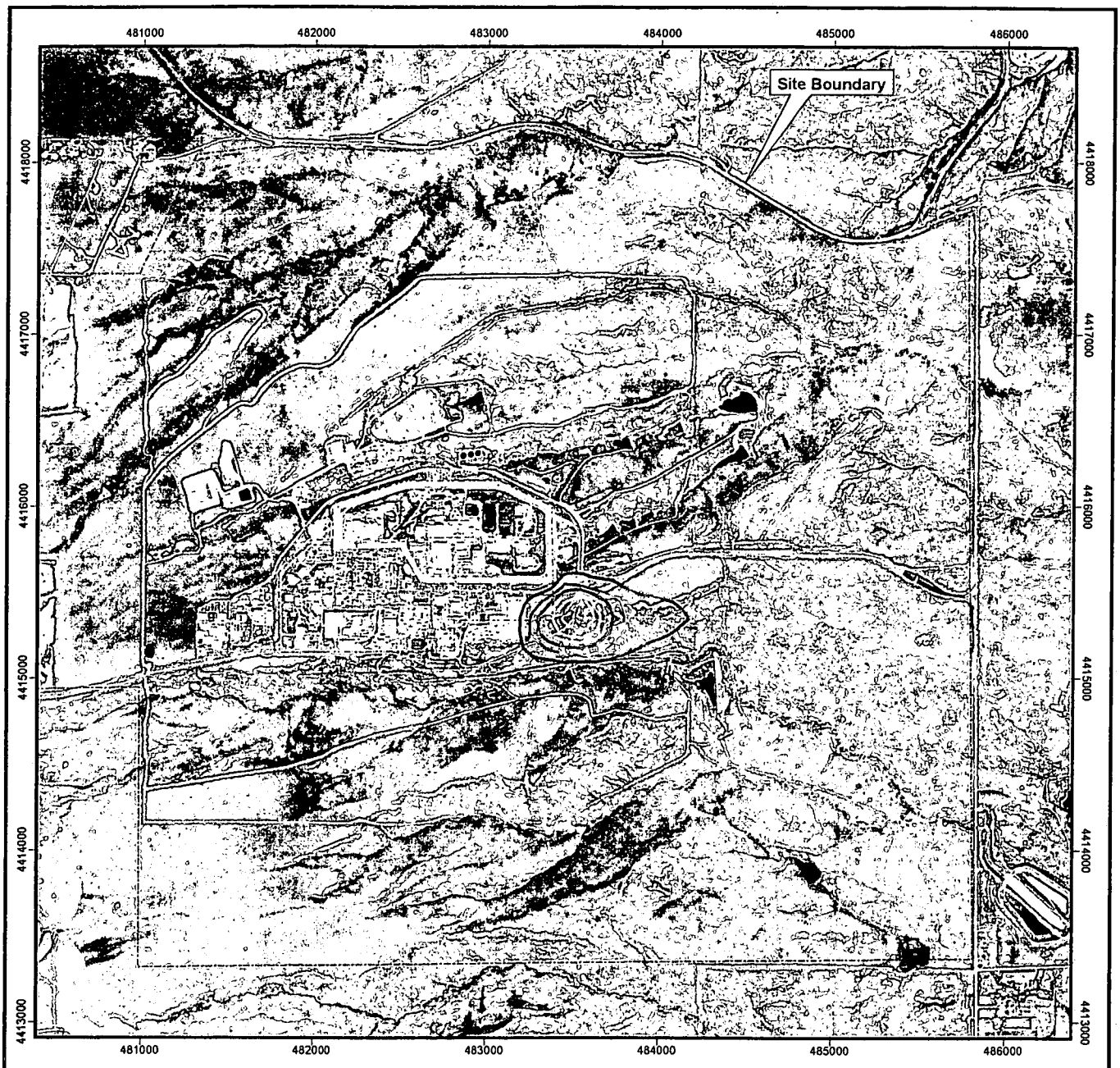


Annual Average Concentration of Activity for Am-241 (pCi/m^3)

2.0E-005
1.2E-004
2.2E-004
3.2E-004
4.2E-004
5.2E-004
6.2E-004

N

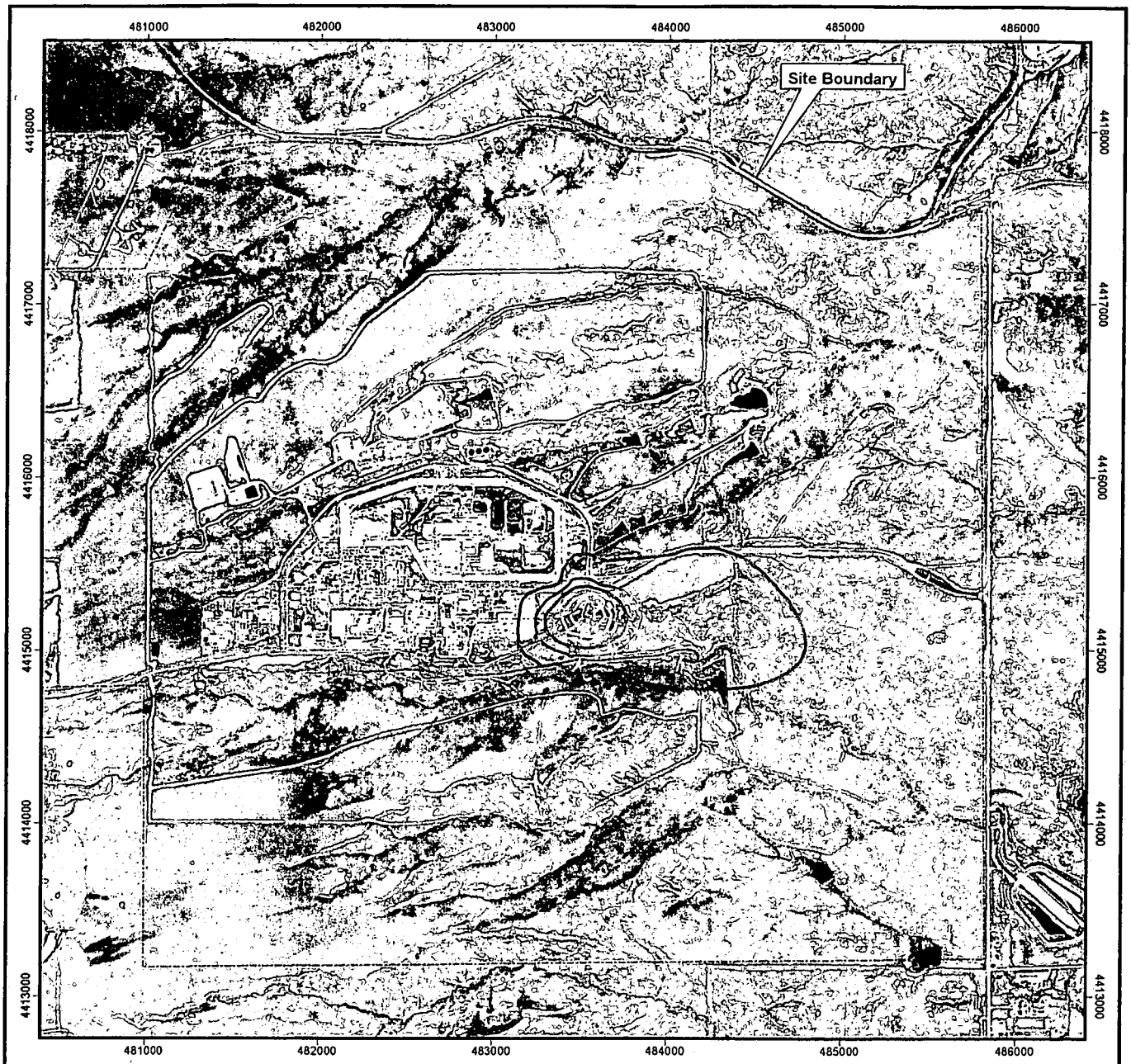
0.5 0 0.5 1 1.5 Kilometers

NOTE:
Coordinates reference
UTM Meters, Zone 13, NAD27

Figure E2-10. Post-Fire Scenario Base Case for Pre-Closure Fire: Estimated Annual Average Concentration Distribution for Am-241

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

APPLICATION	DATE	DR. BY
figse2.apr	09/26/2000	dc



Annual Average Concentration of Activity for Am-241 (pCi/m^3)

- 2.0E-005
- 2.2E-004
- 4.2E-004
- 6.2E-004
- 8.2E-004
- 1.0E-003
- 1.2E-003

N

0.5 0 0.5 1 1.5 Kilometers

NOTE:
Coordinates reference
UTM Meters, Zone 13, NAD27

Figure E2-11. Post-Fire Scenario - Recovery from Case 1 Pre-Closure Fire: Estimated Annual Average Concentration Distribution for Am-241

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

APPLICATION	DATE	DR. BY
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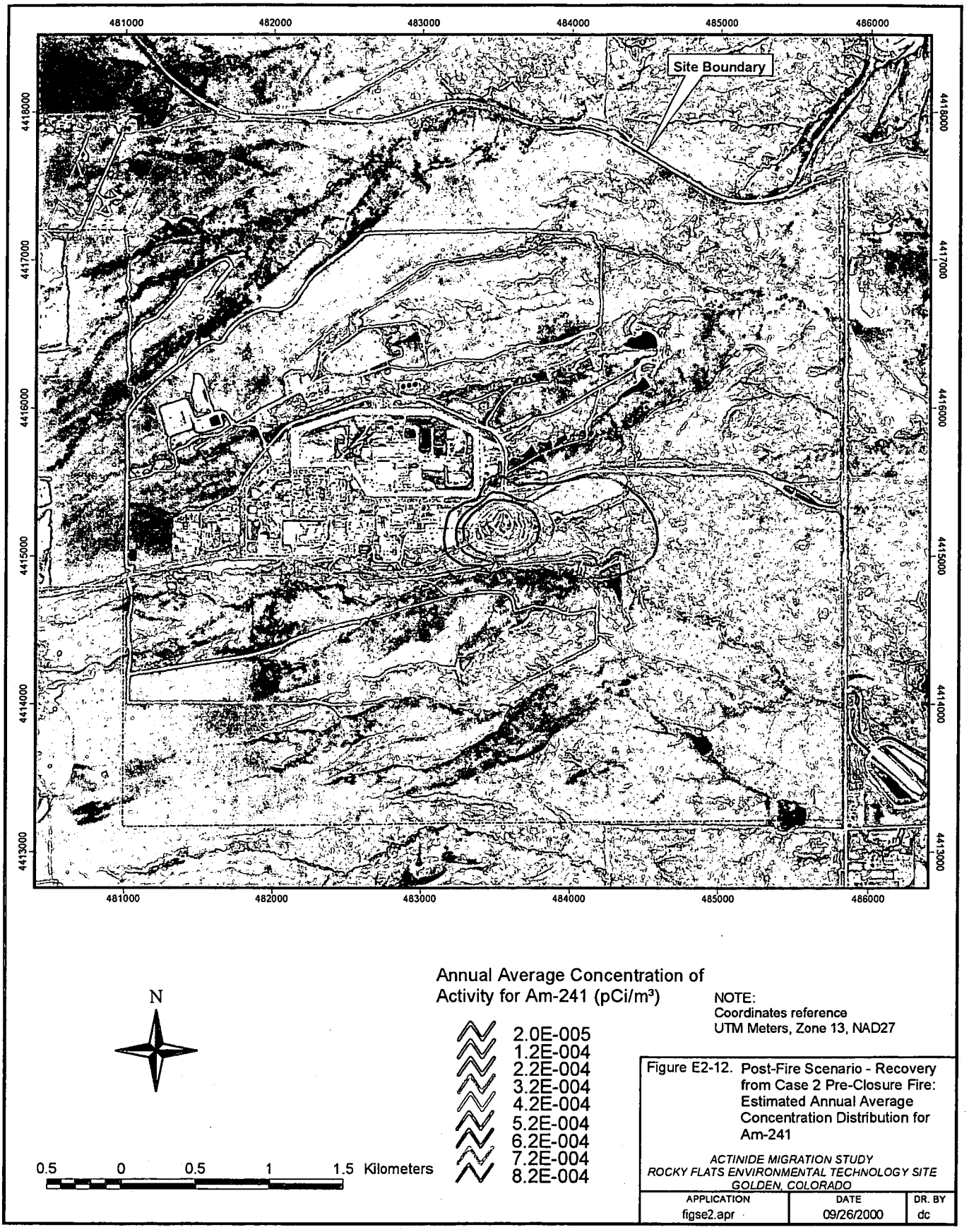

Figure E2-12. Post-Fire Scenario - Recovery from Case 2 Pre-Closure Fire: Estimated Annual Average Concentration Distribution for Am-241

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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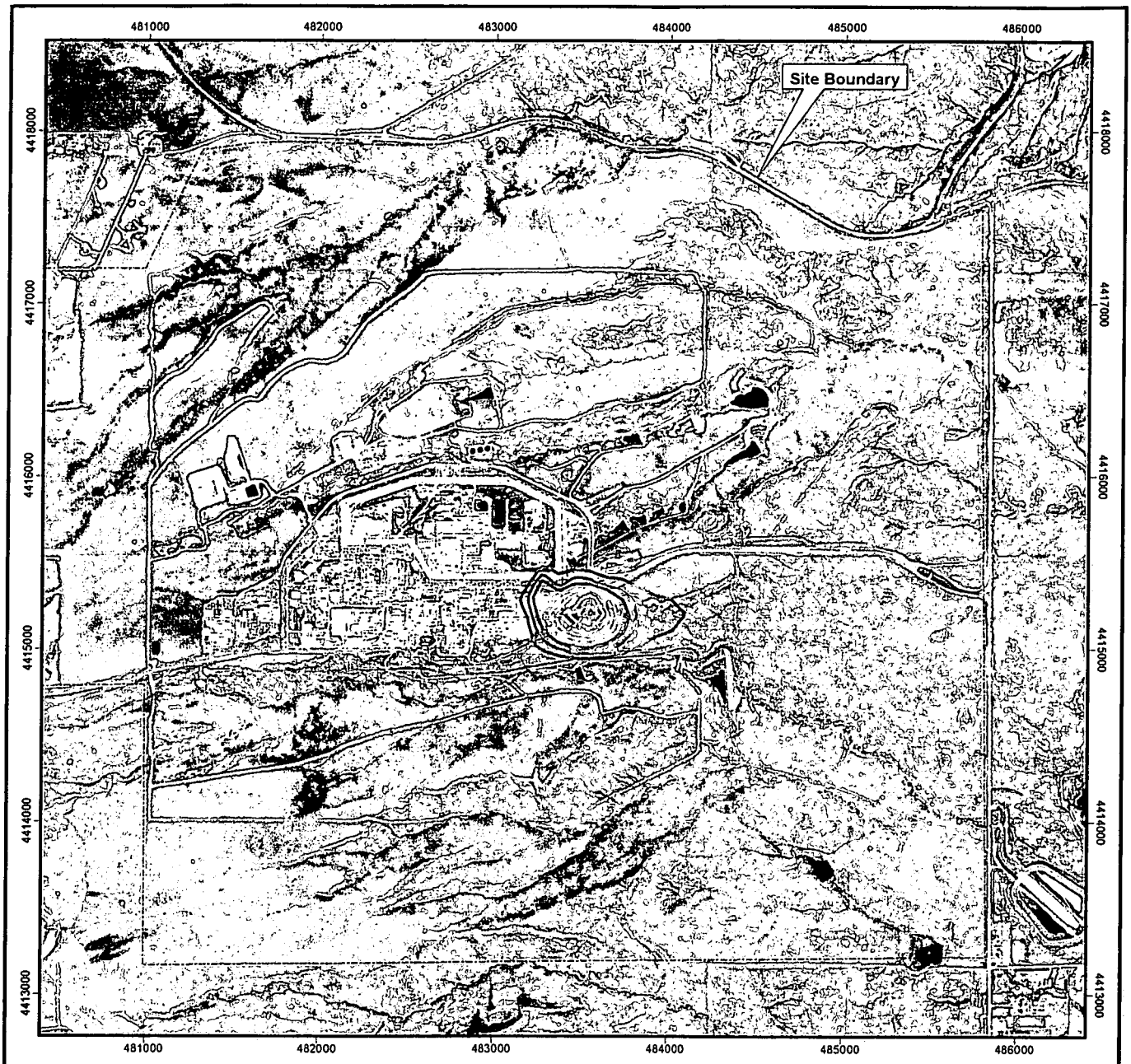

Annual Average Concentration of Activity for Pu-239/240 (pCi/m³)

1.0E-004
6.0E-004
1.1E-003
1.6E-003
2.1E-003
2.6E-003
3.1E-003
3.6E-003
4.1E-006
4.6E-003

N

0.5 0 0.5 1 1.5 Kilometers

NOTE:
Coordinates reference
UTM Meters, Zone 13, NAD27

Figure E2-13. Post-Fire Scenario Base Case for Post-Closure Fire: Estimated Annual Average Concentration Distribution for Pu-239/240

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ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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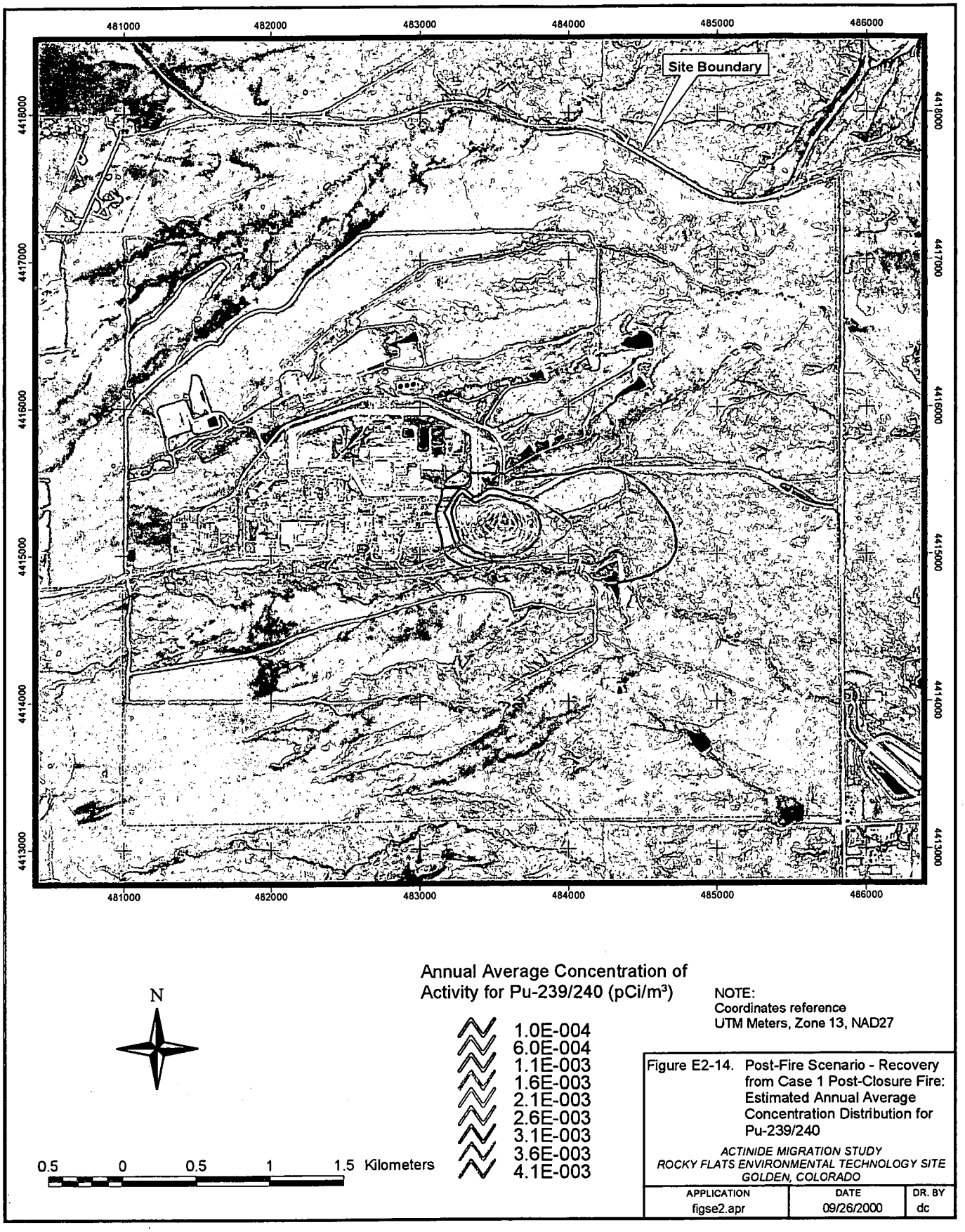

Figure E2-14. Post-Fire Scenario - Recovery from Case 1 Post-Closure Fire: Estimated Annual Average Concentration Distribution for Pu-239/240

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

APPLICATION	DATE	DR. BY
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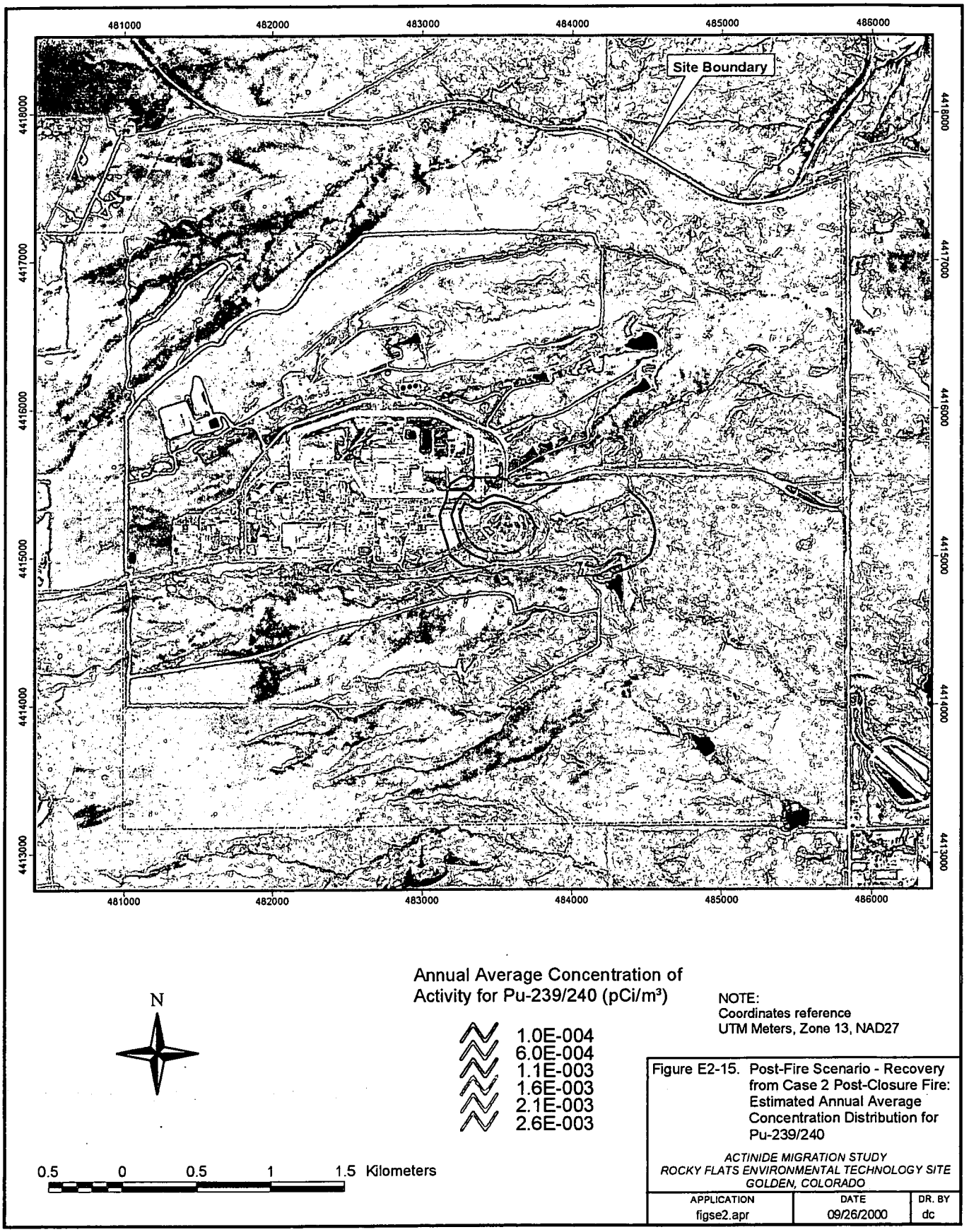

Figure E2-15. Post-Fire Scenario - Recovery from Case 2 Post-Closure Fire: Estimated Annual Average Concentration Distribution for Pu-239/240

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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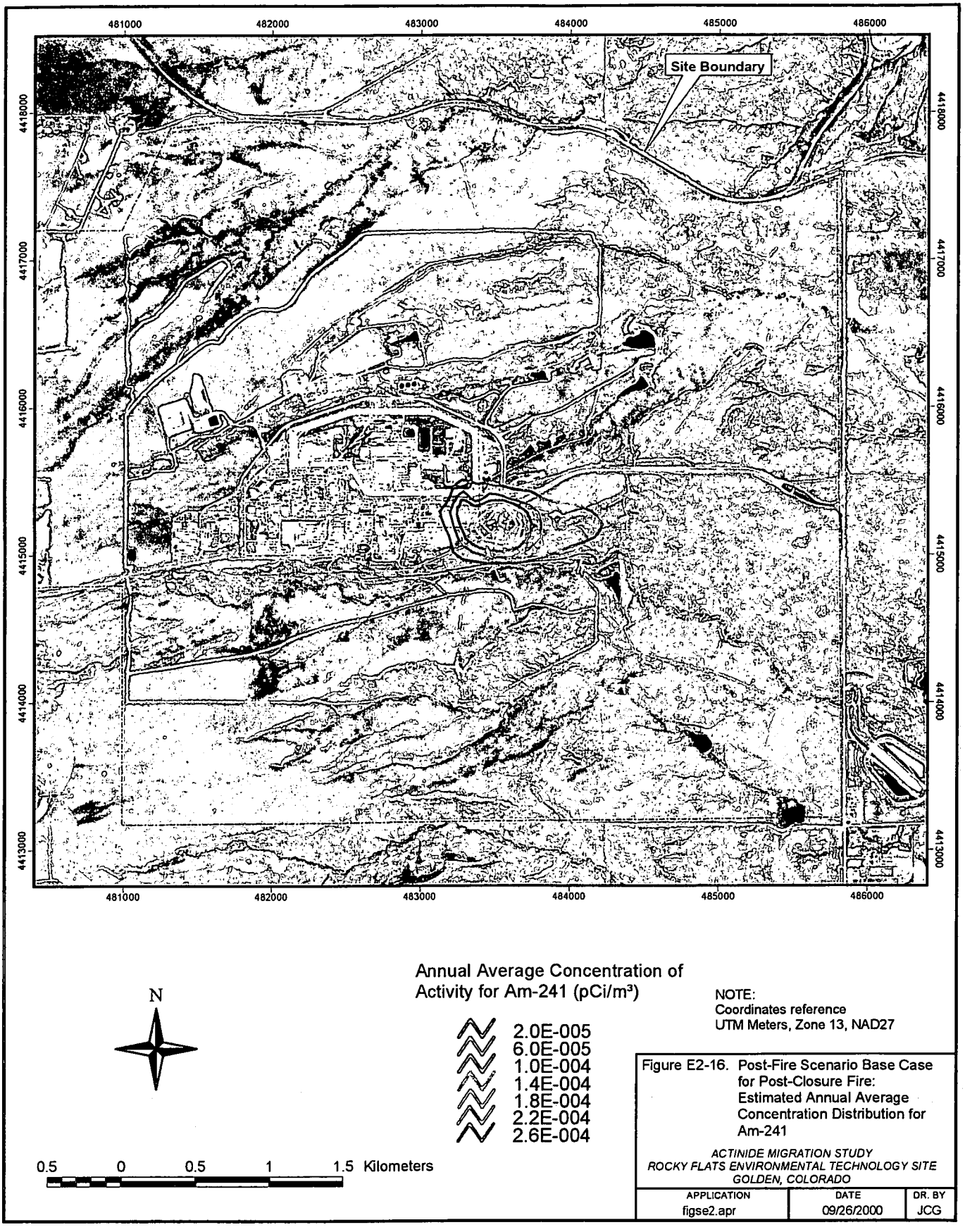

Figure E2-16. Post-Fire Scenario Base Case for Post-Closure Fire: Estimated Annual Average Concentration Distribution for Am-241

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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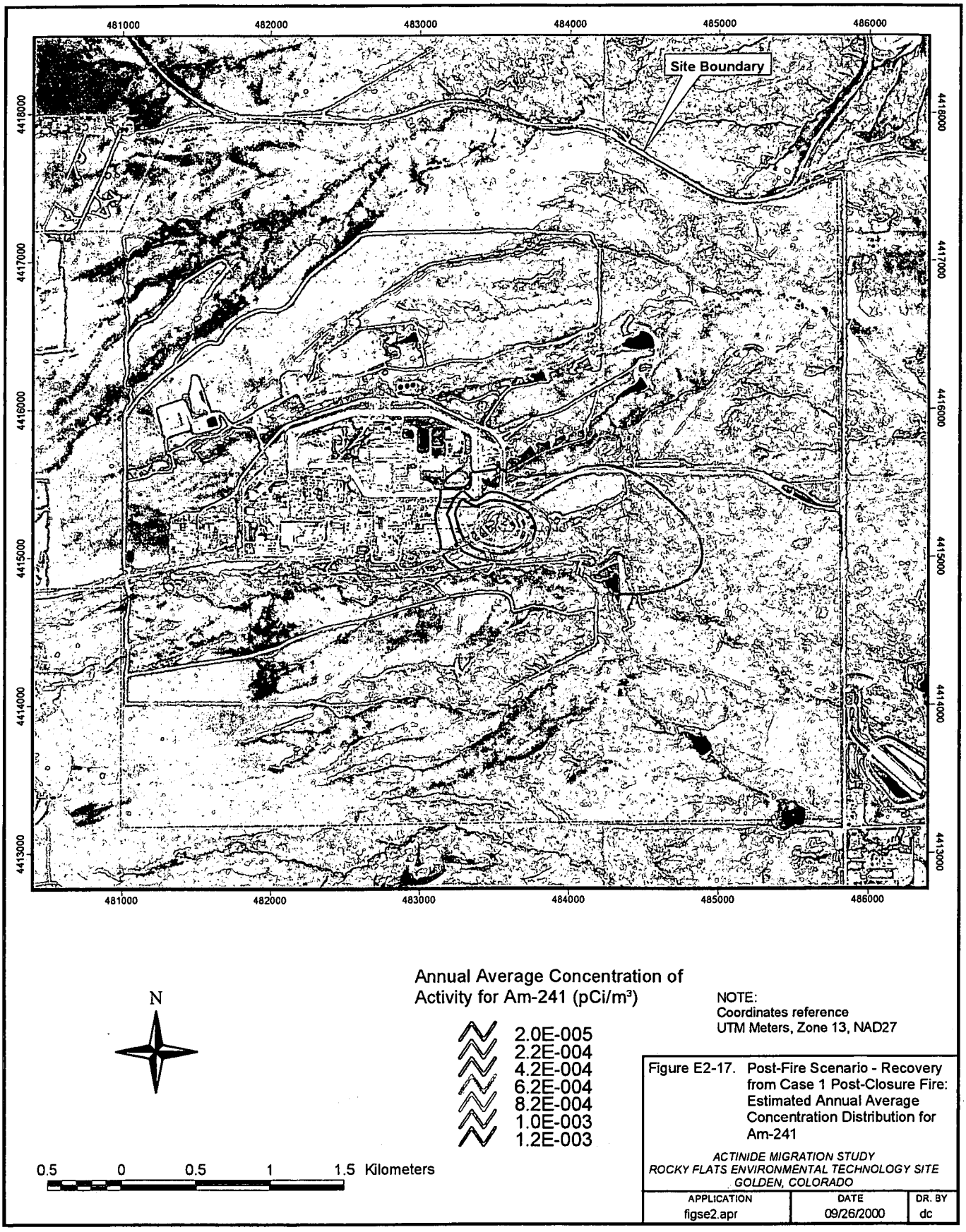

Figure E2-17. Post-Fire Scenario - Recovery from Case 1 Post-Closure Fire: Estimated Annual Average Concentration Distribution for Am-241

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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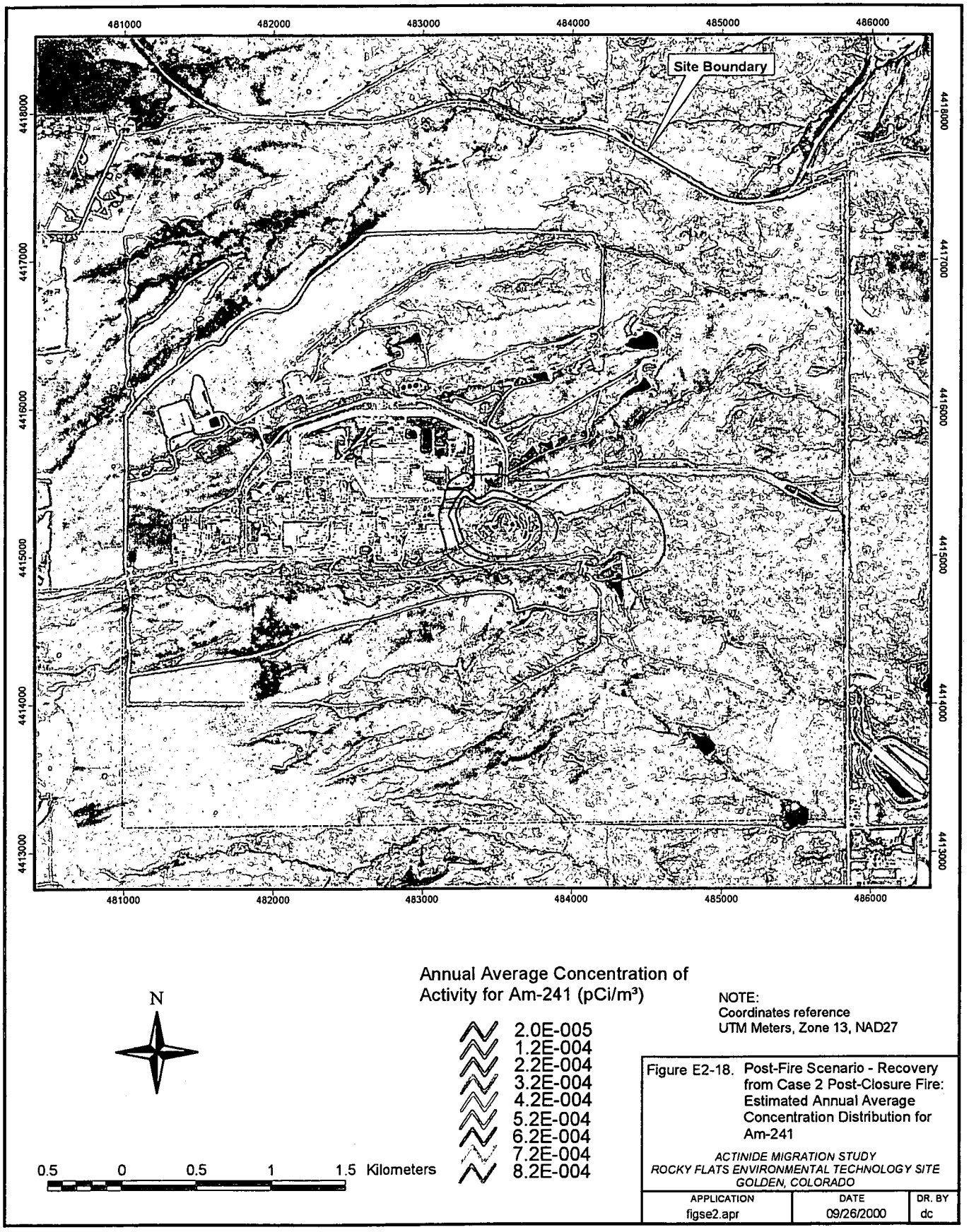

Figure E2-18. Post-Fire Scenario - Recovery from Case 2 Post-Closure Fire: Estimated Annual Average Concentration Distribution for Am-241

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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Appendix F

Post-Closure Resuspension Scenario Modeling Results

APPENDIX F

POST-CLOSURE RESUSPENSION SCENARIO MODELING RESULTS

The modeling results for Scenario 5 are shown in Figures F-1 through F-10.

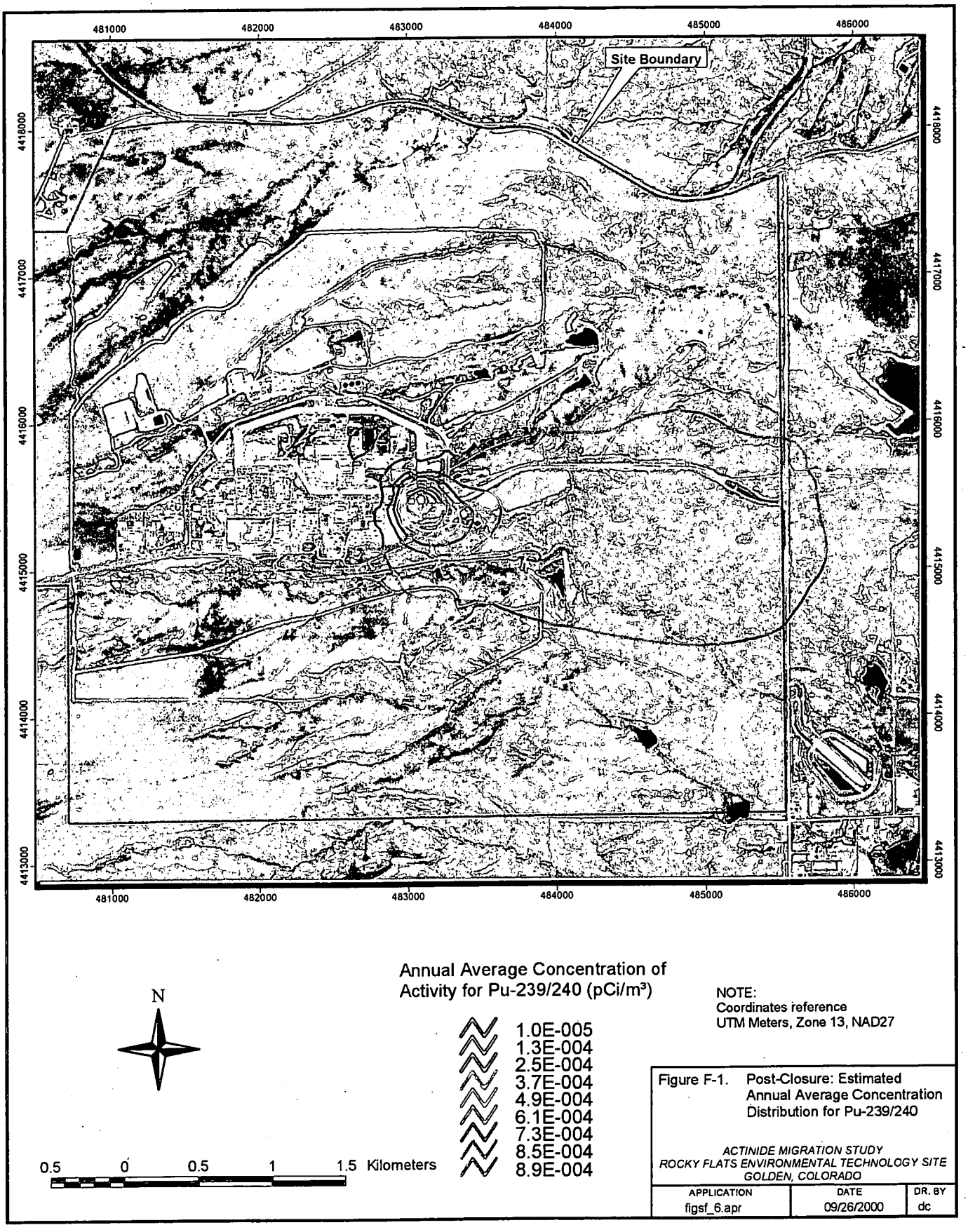

Figure F-1. Post-Closure: Estimated Annual Average Concentration Distribution for Pu-239/240

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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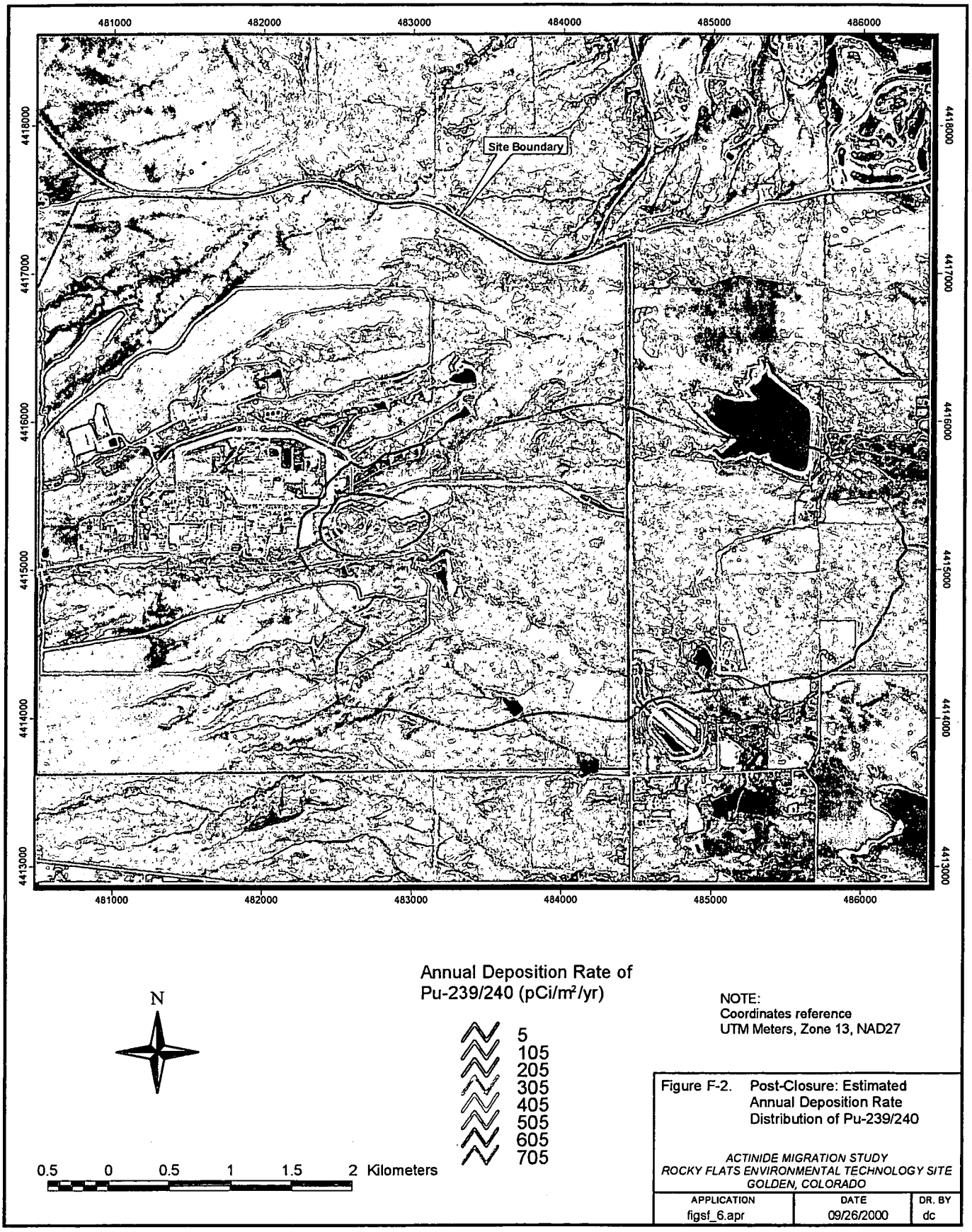

Figure F-2. Post-Closure: Estimated Annual Deposition Rate Distribution of Pu-239/240

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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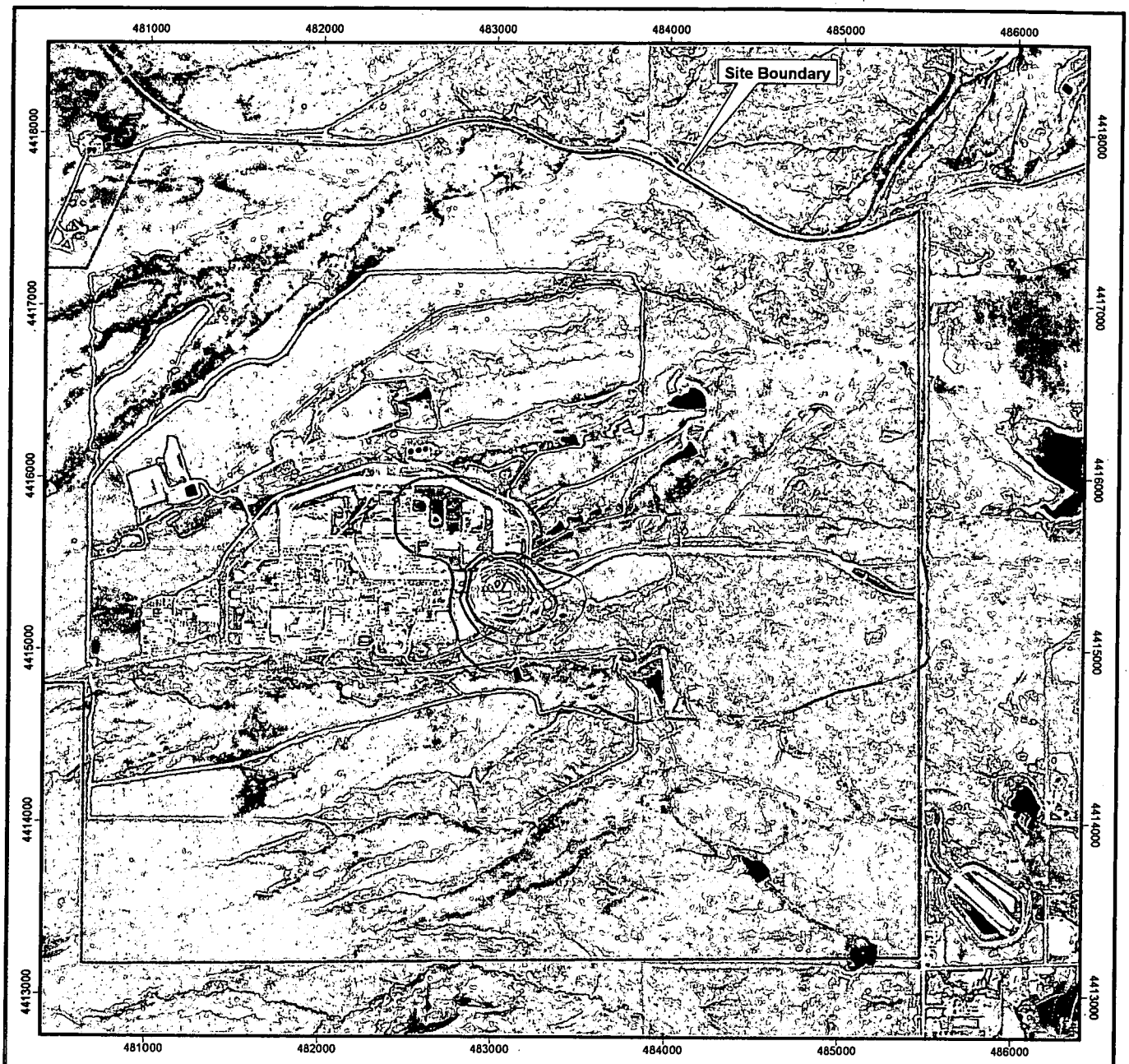

Annual Average Concentration of Activity for Am-241(pCi/m³)

- 2.0E-006
- 1.7E-005
- 3.2E-005
- 4.7E-005
- 6.2E-005
- 7.7E-005
- 9.2E-005
- 1.1E-004
- 1.2E-004
- 1.4E-004

N

0.5 0 0.5 1 1.5 Kilometers

NOTE:
Coordinates reference
UTM Meters, Zone 13, NAD27

Figure F-3. Post-Closure: Estimated Annual Average Concentration Distribution for Am-241

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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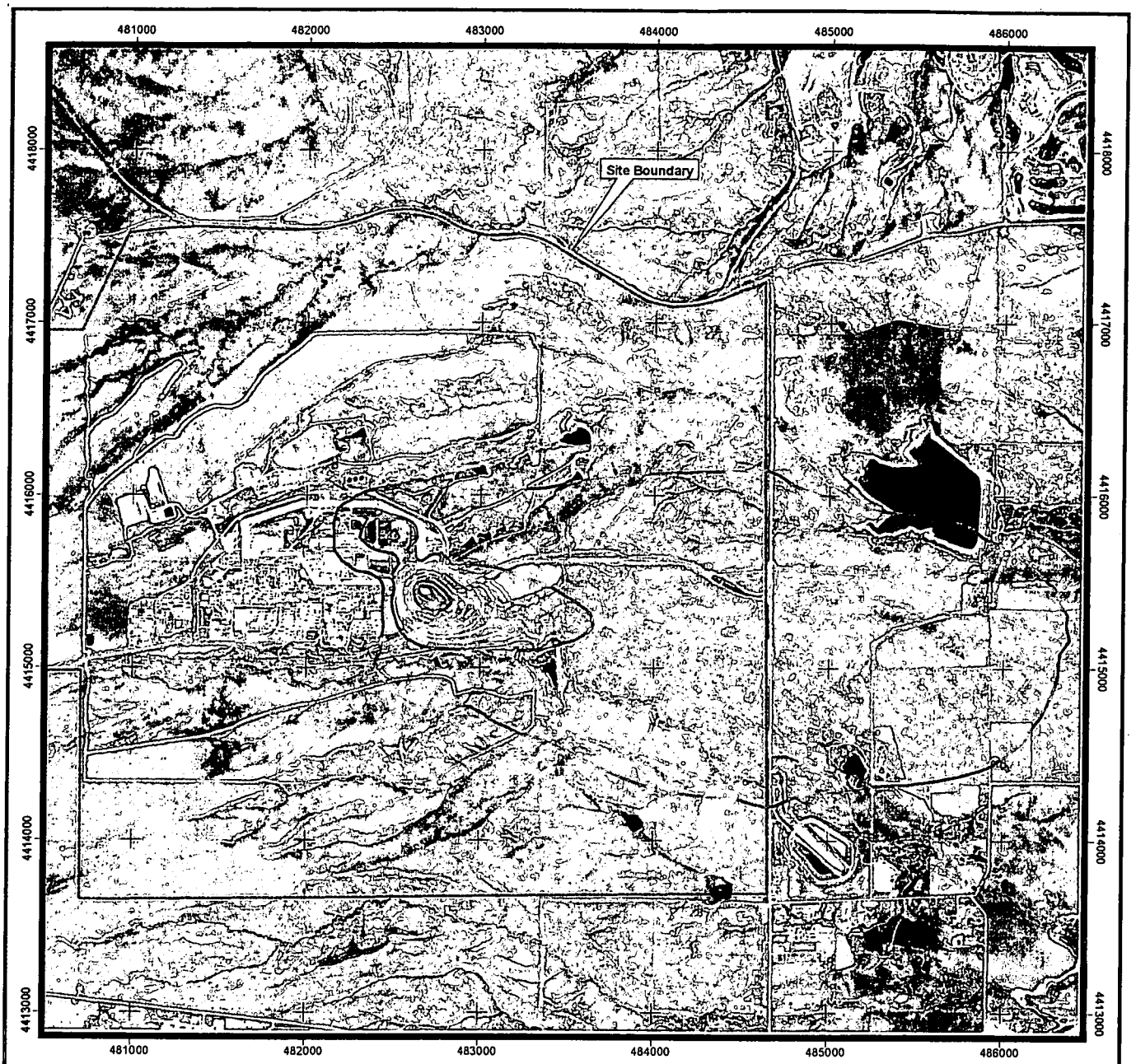

Annual Deposition Rate of
Am-241 (pCi/m²/yr)

1
11
21
31
41
51
61
71
81
91
101
111

N

0.5 0 0.5 1 1.5 2 Kilometers

NOTE:
Coordinates reference
UTM Meters, Zone 13, NAD27

Figure F-4. Post-Closure: Estimated Annual Deposition Rate Distribution of Am-241

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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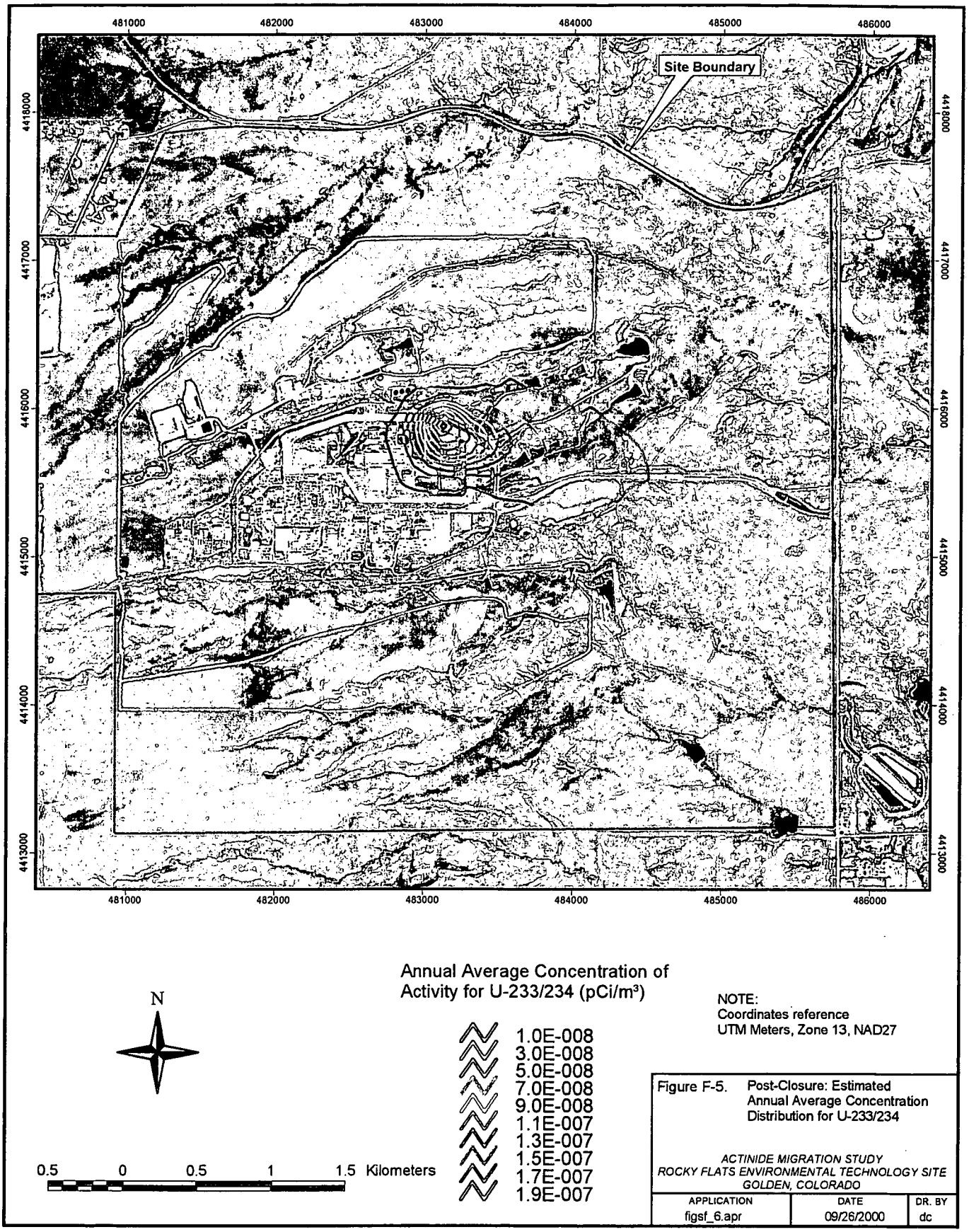

Figure F-5. Post-Closure: Estimated Annual Average Concentration Distribution for U-233/234

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

APPLICATION	DATE	DR. BY
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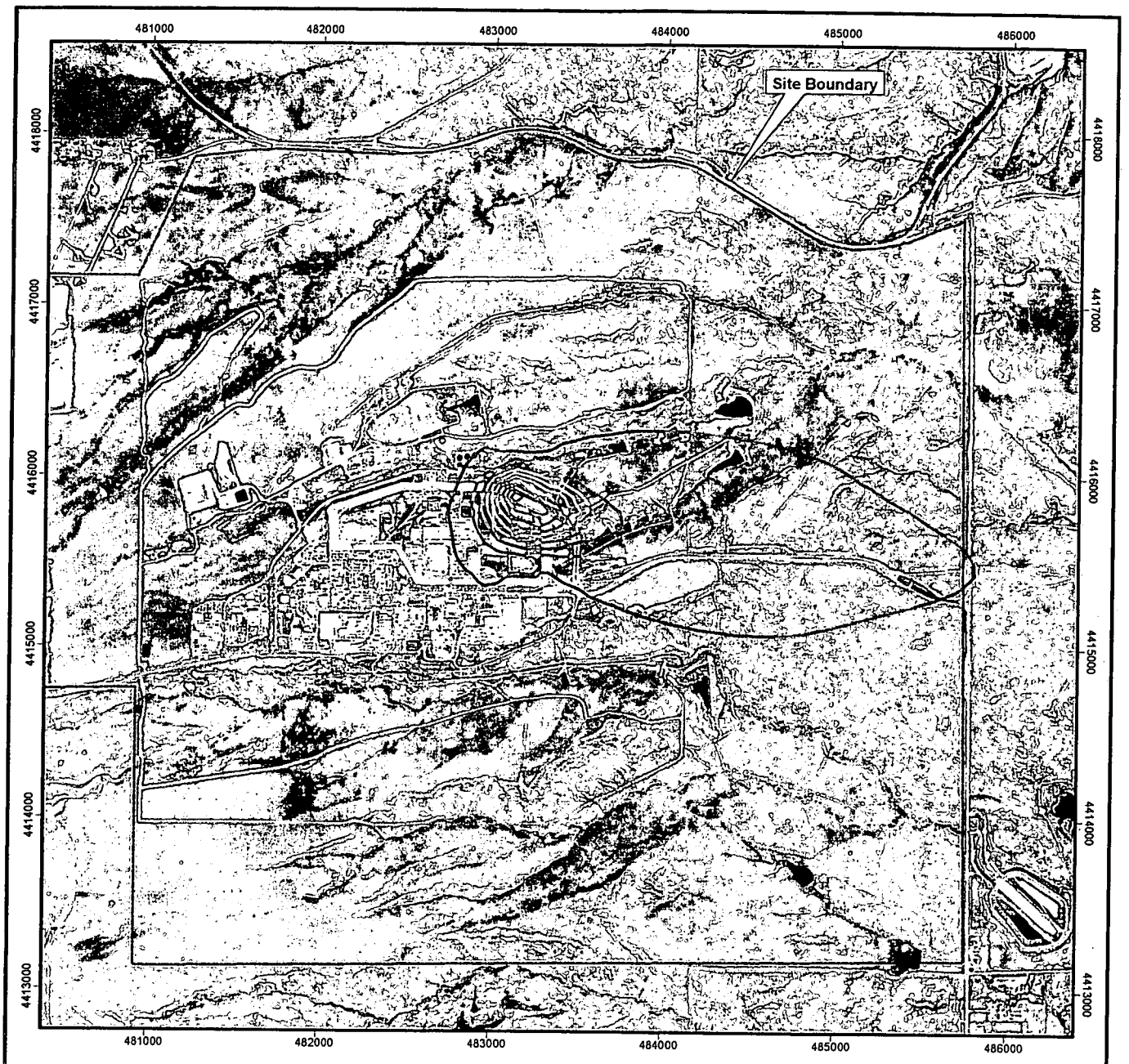

Annual Deposition Rate of
U-233/234 (pCi/m²/yr)

0.01
0.05
0.09
0.13
0.17
0.21
0.25
0.29
0.33

N

0.5 0 0.5 1 1.5 Kilometers

NOTE:
Coordinates reference
UTM Meters, Zone 13, NAD27

Figure F-6. Post-Closure: Estimated Annual Deposition Rate Distribution of U-233/234

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

APPLICATION	DATE	DR. BY
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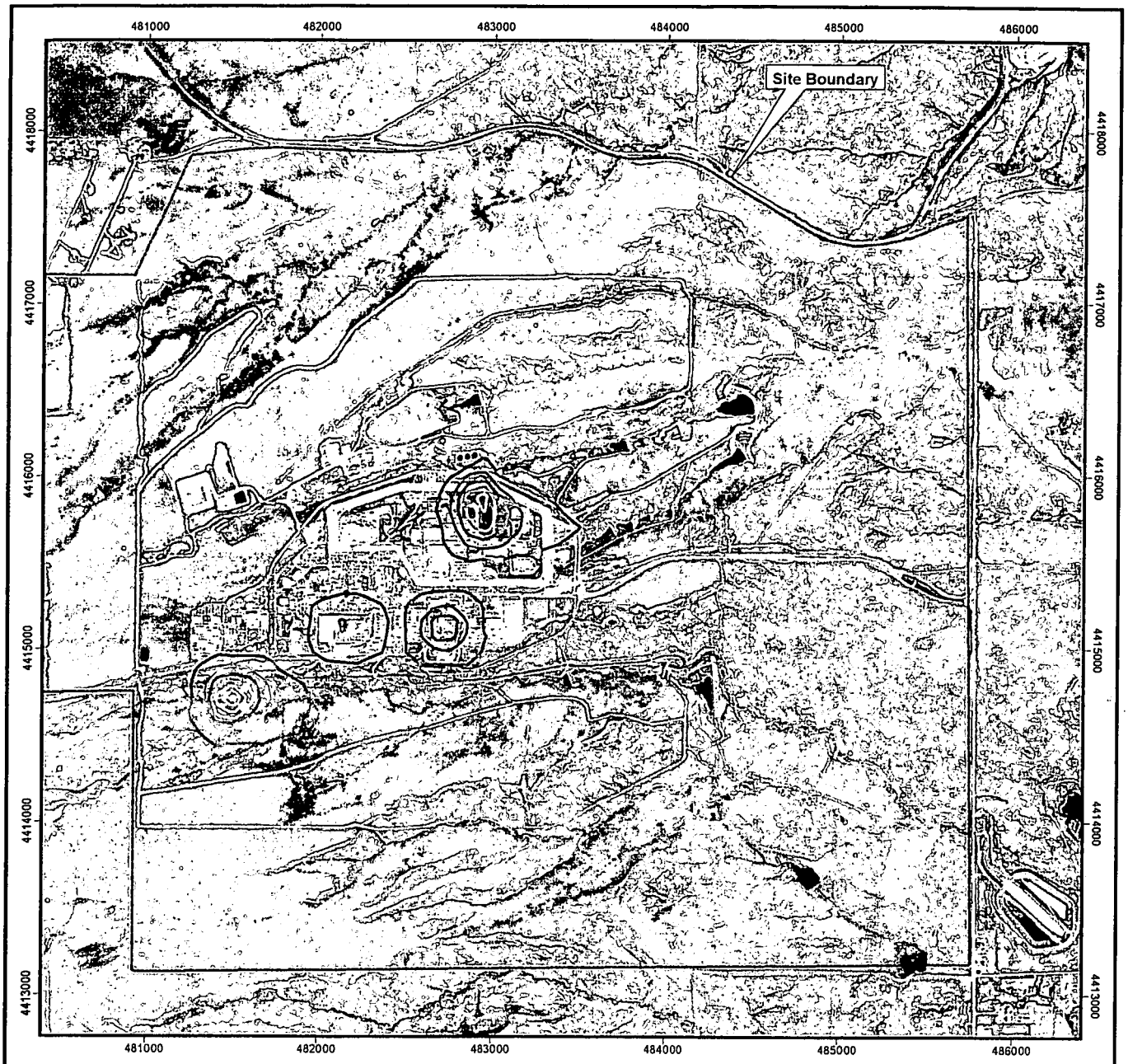

Annual Average Concentration of Activity for U-235 (pCi/m³)

1.0E-008
5.0E-008
9.0E-008
1.3E-007
1.7E-007
2.1E-007
2.5E-007

N

0.5 0 0.5 1 1.5 Kilometers

NOTE:
Coordinates reference
UTM Meters, Zone 13, NAD27

Figure F-7. Post-Closure: Estimated Annual Average Concentration Distribution for U-235

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

APPLICATION	DATE	DR. BY
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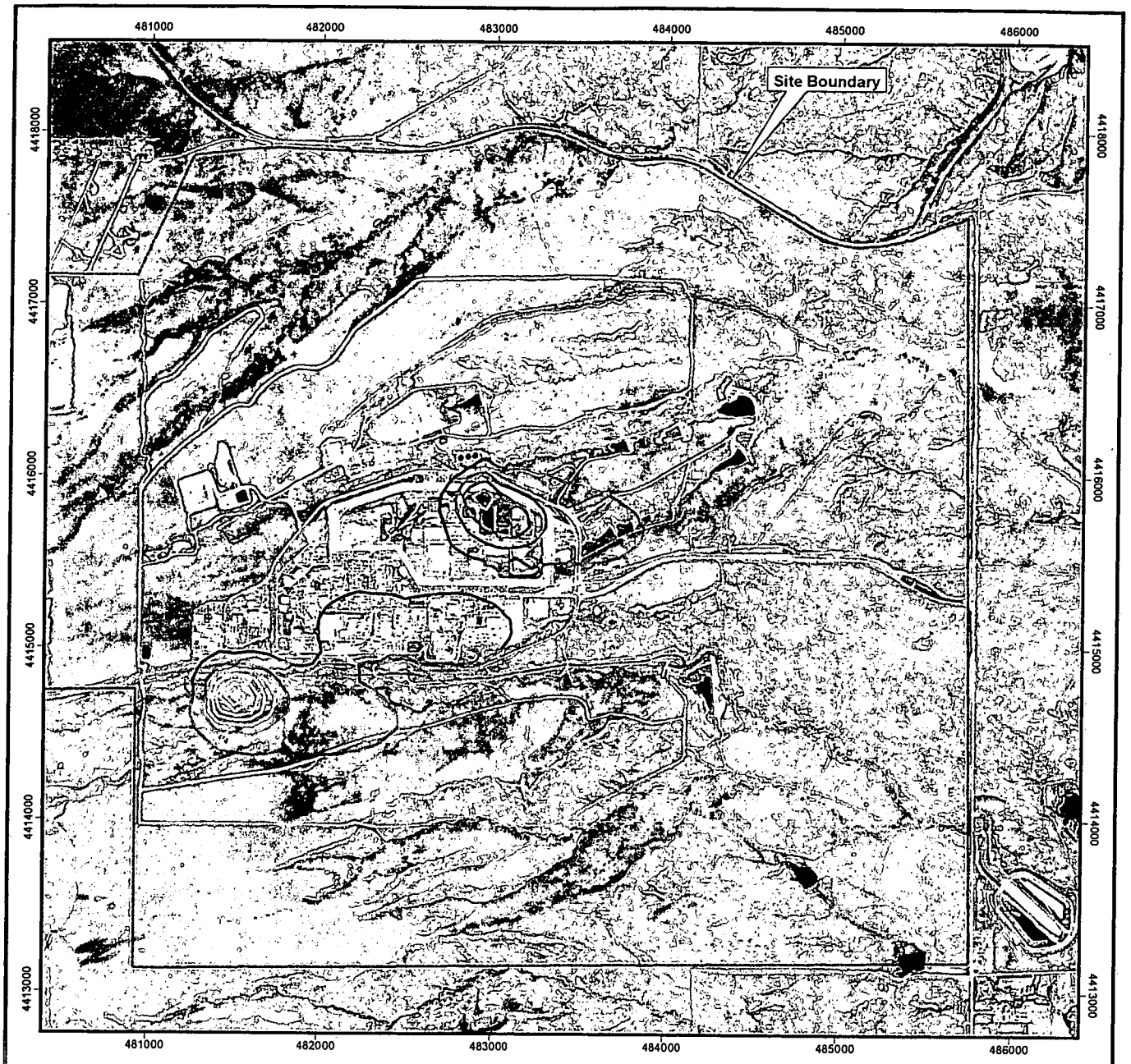

Annual Deposition Rate of
U-235 (pCi/m²/yr)

0.01
0.05
0.09
0.13
0.17
0.21
0.25
0.29
0.33

N

0.5 0 0.5 1 1.5 Kilometers

NOTE:
Coordinates reference
UTM Meters, Zone 13, NAD27

Figure F-8. Post-Closure: Estimated Annual Deposition Rate Distribution of U-235

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

APPLICATION	DATE	DR. BY
figsf_6.apr	09/26/2000	dc

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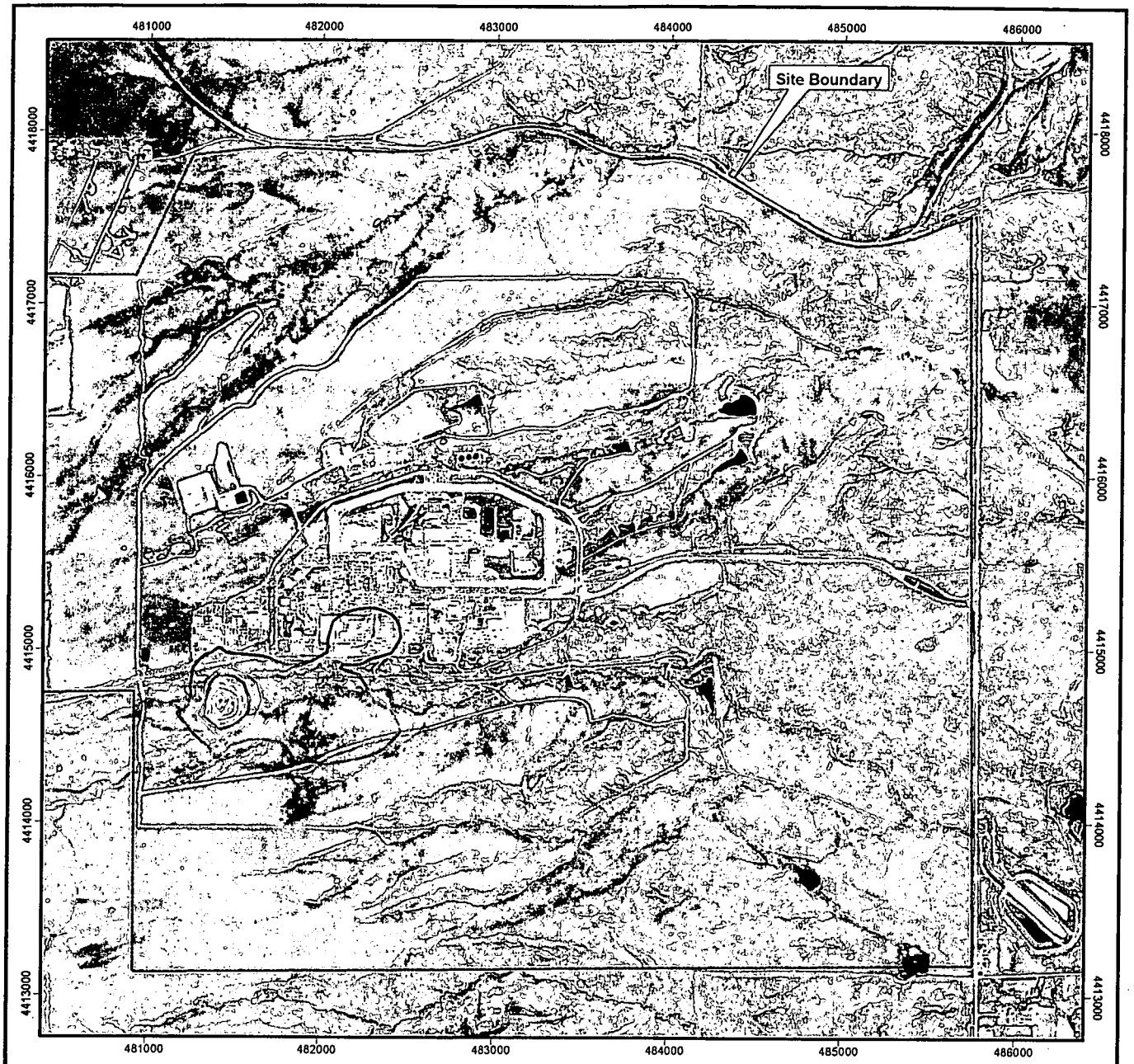

Figure F-9. Post-Closure: Estimated Annual Average Concentration Distribution for U-238

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

APPLICATION	DATE	DR. BY
figsf_6.apr	09/26/2000	dc

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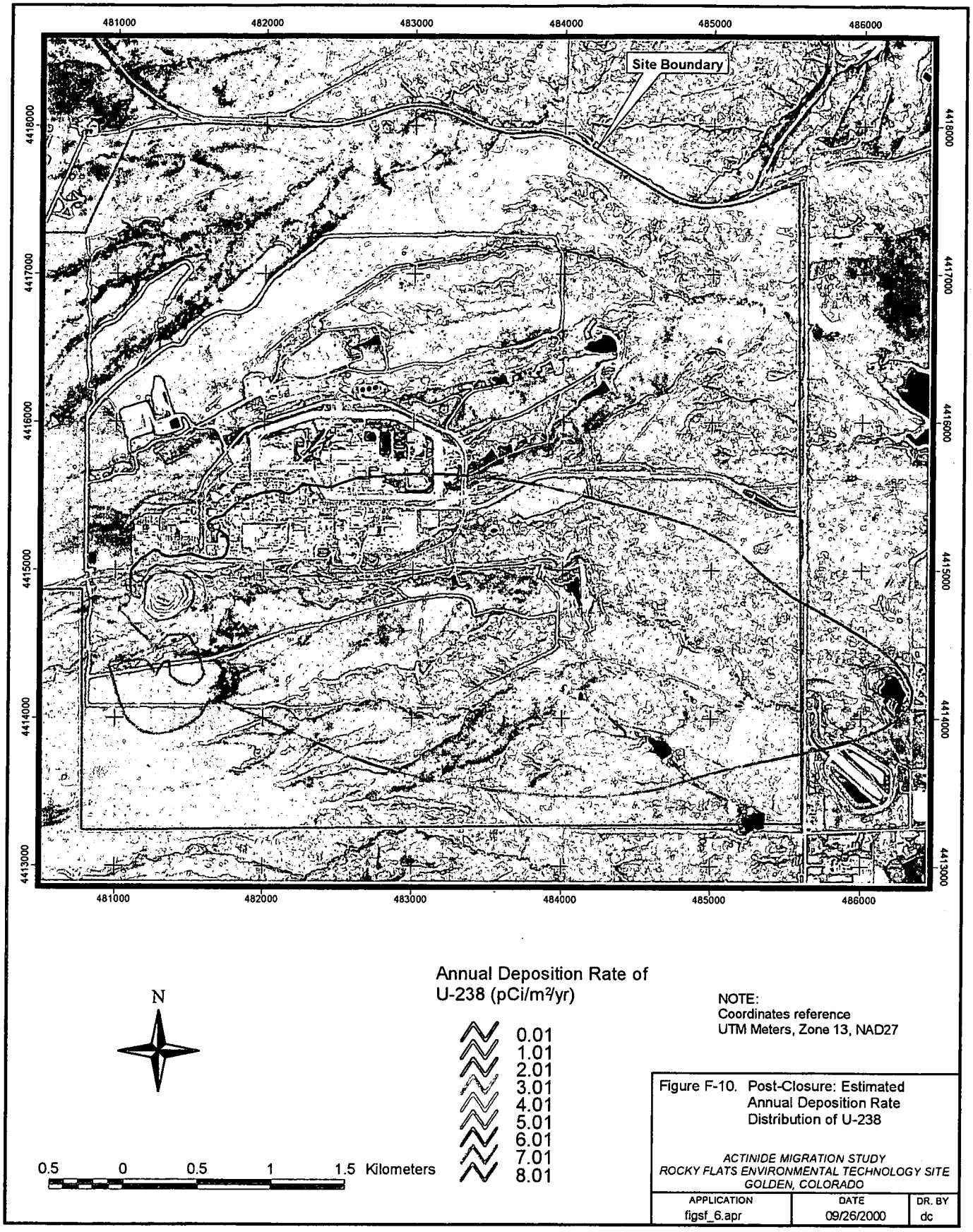

Figure F-10. Post-Closure: Estimated Annual Deposition Rate Distribution of U-238

ACTINIDE MIGRATION STUDY
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

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